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THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

Edited by

GEORGE E. HALE
Mount Wilson Observatory of the Carnegie
Institution of Washington

EDWIN B. FROST
Yerkes Observatory of the
University of Chicago

HENRY G. GALE
Ryerson Physical Laboratory of the
University of Chicago

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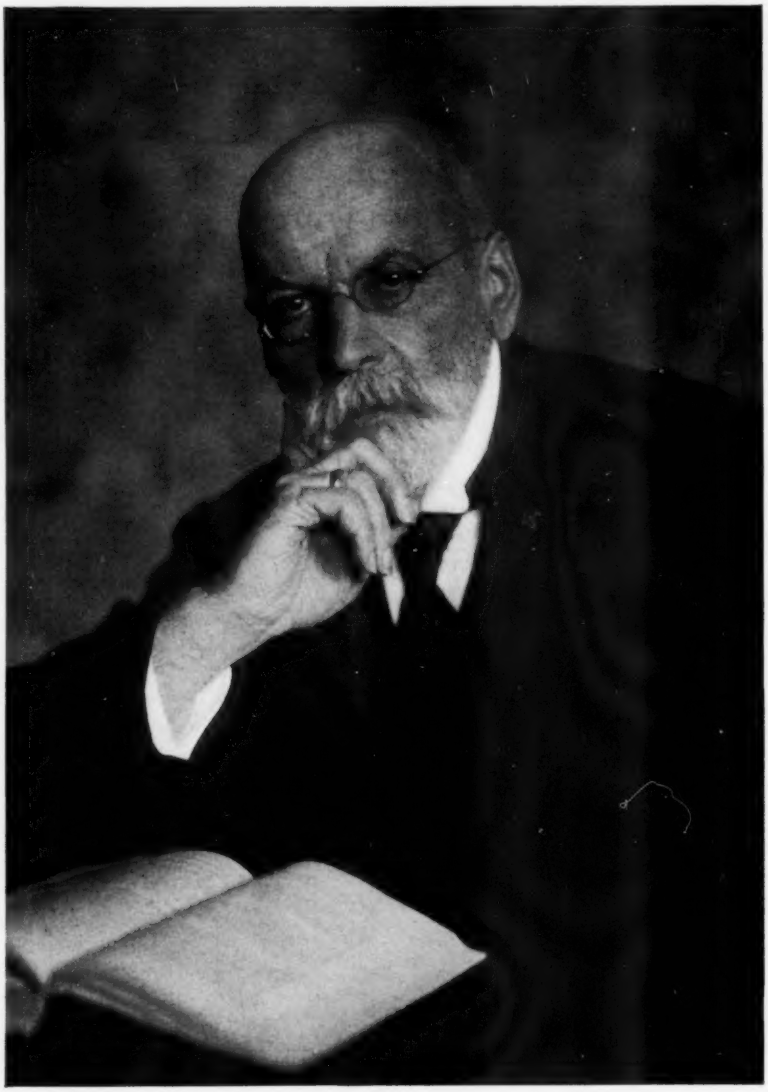

GUSTAV MÜLLER

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GUSTAV MÜLLER

By WILHELM MÜNCH

Gustav Müller was born on May 7, 1851, in Schweidnitz, Silesia, where his father was a merchant. After completing his studies at the Gymnasium in that town, he entered the University of Leipzig in 1870, with a view to further study of mathematics and the physical sciences. After two years he migrated to the University of Berlin, where he was led by the influence of Wilhelm Förster to devote himself to astronomy. After some work as computer for the *Berliner Jahrbuch* and a short period of activity under A. Auwers, he came, about 1875, into association with H. C. Vogel, who was then engaged in spectroscopic work at the Berlin Observatory. He received the degree of Doctor of Philosophy from the University of Berlin in 1877, his thesis being an investigation of micrometer screws. Thereafter he accepted an appointment as assistant in the Astrophysical Observatory at Potsdam, which was in process of establishment by Vogel. To this institution he devoted the rest of his scientific career.

Müller's activity in research was chiefly directed to two fields, the solar spectrum and celestial photometry. His work in the first of these began at Berlin in measuring photographs of the solar spectrum made by H. C. Vogel, which was later published in a paper by the latter.[1] He thus found a line of work which held his interest

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[1] *Publikationen des Astrophysikalischen Observatoriums zu Potsdam*, No. 3. These publications will be designated hereafter in this article merely by the number of the particular *Stück*.

throughout his whole life. His first publication upon this subject appeared as early as 1881,[1] and was followed in 1886 by a more extensive investigation of the same matter, in collaboration with P. Kempf.[2] The study of terrestrial lines in the solar spectrum, which he had taken up on the occasion of his visit to the peak of the Sentis, occupied his attention to a considerable extent from 1902 to 1906. During these years he took not less than five hundred plates, on each of which he brought into juxtaposition the spectrum of the opposite points of the sun's equator. He was, however, never able to finish this research.

In the field of stellar spectroscopy Müller worked only during the years 1880–1882, when he assisted Vogel in his visual *Durchmusterung* of stellar spectra.[3] This work was, however, of significance to Müller, in that it suggested to him the photometric *Durchmusterung* of the stars, which he later completed in collaboration with Kempf.

Müller's first incentive to undertake photometric investigations came at Berlin, when he assisted Vogel in determining the distribution of brightness upon the solar disk. As early as 1877, at Potsdam, Müller began his photometric observations of the brightness of the planets and on the extinction of light in the atmosphere. His first communication on this subject appeared in 1883.[4] In 1893, he published an extensive investigation on the planets.[5] To the extinction of light he devoted longer investigations, the first of which led him to the Sentis in 1889.[6] The second expedition, made in 1894, in collaboration with Kempf, went to Catania and Mount Etna.[7] On the third trip, in 1910, when he was fifty-nine years old, he went to the peak of Teneriffe[8] with E. Kron.

The center of gravity and the most significant feature of Müller's distinguished life-work lay in the field of celestial photometry. Here we must name three great undertakings in which he had the collaboration of other astronomers. These, however, were the result of his initiative, and in them he was throughout the most active force. He carried on these researches with the greatest endurance and vigor, and pushed them through to the end. The first of these was

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[1] No. 6. [2] No. 20. [3] No. 11. [4] No. 12. [5] No. 30. [6] No. 27. [7] No. 38.

[8] *Astronomische Nachrichten*, **103**, 241, 1882; No. 64.

the Potsdam photometric *Durchmusterung* of the northern heavens, contained in Nos. 31, 43, 44, and 51, the final results of which are collected in No. 52, which constitutes volume 17 of the Potsdam *Publications*. The second undertaking was the catalogue, *Geschichte und Literatur des Lichtwechsels der bis Ende 1915 als sicher veränderlich anerkannten Sterne*. This was edited by a committee of the Astronomische Gesellschaft, of which Müller was chairman. The three separate volumes were published in 1918, 1920, and 1922. Of the last of his large undertakings, which was to be a photometric *Durchmusterung* of all B.D. stars between +80° and the north pole included between the magnitudes 7.5 and 9.5, there has appeared in print only a communication on the brightness of 253 control stars in the zone between +75° and the north pole.

Of the many photometric researches by Müller which were published in the *Astronomische Nachrichten*, we may cite, in particular, the determination of the brightness of ninety-six stars of the Pleiades.[1] This work was done in collaboration with Kempf, as was another important investigation of the relation between color-index and magnitudes of the stars and the relation of the star colors to the Milky Way.[2]

In addition to his abundant scientific activity, Müller found time for writing his manual entitled *Die Photometrie der Gestirne*, which appeared in 1897. This presents in an admirable manner the knowledge of this branch up to that time. Mention should also be made of his work on the effects of temperature upon the refraction of light in certain varieties of glass, in calcspar, and in quartz.[3]

Müller took part in three expeditions besides those which have already been mentioned, namely, that to Hartford, Connecticut, in 1882, for the observation of the transit of Venus; in 1887, to Russia, for the observation of the total solar eclipse; in 1900, to Portugal, for photometric observations of Mercury during the total eclipse. The last two expeditions were not favored with fair weather.

Müller did not lack recognition for his services to astronomy. From 1896 to 1924 he was one of the secretaries of the Astronomische Gesellschaft. He was elected a member of the Prussian Academy of Sciences in Berlin in 1918. From 1917 to 1921 he was director of the

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[1] *Ibid.*, **150**, 193, 1899.

[2] *Ibid.*, **180**, 250, 1909.

[3] No. 16.

Astrophysical Observatory at Potsdam. According to the law of the Prussian State, it was necessary for him to retire in 1921, at the age of seventy, but he remained in close connection with the Observatory.

Müller had always enjoyed the best of health, and it was not until the winter of 1924–1925 that the first sign appeared of an internal disorder which, after an unsuccessful operation, brought his energetic and successful life to a close on July 7, 1925.

Müller was married three times. He had seven children, of whom five survive, with his widow. He lost one son during the war and another during the disturbances following.

Research in astronomy was the strongest passion of Müller's life. His successful career was greatly due to his unusual capacity for work, as well as to his well-formed plans for his researches and the conscientious perseverance with which he prosecuted them. In his judgment he was critical and cool, and he was not inclined toward speculation. He preferred to tread on safe ground, according to the old school, and he undertook problems which lay in the range of possible accomplishment and guaranteed certain steps of progress.

Müller was a man of simple, upright, noble character, who laid upon himself, as upon others, high demands. He was characterized by a far-reaching interest in the welfare of others, particularly of his subordinates. Naturally of a friendly disposition, he greatly enjoyed social gatherings, and, especially in the early years, kept his house open to guests. Thus he did much to maintain the friendly relations of his circle. His wide experience of life and his mental alertness and friendliness made him exceptionally entertaining, and he was well known as a brilliant after-dinner speaker who availed himself equally well of humor and seriousness. Among the arts he was devoted to classical music, and often entertained his guests with his excellent ability at the piano.

In the history of astronomy Müller will live as one of the creators of modern celestial astronomical photometry, and in the hearts of his friends and admirers he will remain unforgotten as a sincere and kindly man.

[NOTE.—It is a satisfaction to Müller's old friends to know that his son Rolf has chosen astronomy as a profession and has taken a place on the staff of the Potsdam Observatory.—TR.]

THE ZEEMAN EFFECT FOR THE SPECTRUM OF FLUORINE

BY G. HOWARD CARRAGAN

ABSTRACT

An *electromagnet* has been constructed which proves to be suitable for study of the Zeeman effect at high field-strengths.

Certain *improvements in the technique* of handling fluorine have been instituted and a form of discharge tube has been devised which is suitable for giving the fluorine spectrum under high field-strengths.

The red spectrum has been photographed with a grating of high dispersion and the *Zeeman patterns of twenty of the brighter lines determined*.

The analysis of the patterns with a consideration of the ratios of the intervals of wave-number between the lines and the distribution of their relative intensities seems to indicate a *first-order quartet system*. On this basis the term combinations of the principal and diffuse series have been located. Those of other lines have been proposed from a consideration of relationships of the intervals of wave-number and the *possible existence* of the *fluorine ion* and *higher-order spectra* suggested.

Four fluorine lines observed by Gale and Monk, but not given in their published list of wave-lengths, are cited. Three of these have been observed and a fourth inferred from the analysis of the spectrum.

INTRODUCTION

Kayser's *Handbuch der Spectroscopie*, Volume V, cites some ten investigations on the spectrum of fluorine since 1862. The work of Exner and Haschek[1] and of Parlezza[2] has added to our knowledge of the spectrum, while Smythe,[3] working at Ryerson Laboratory, did much to develop the technique of handling fluorine. It remained, however, for Gale and Monk[4] to make the most complete survey of the spectrum and to give wave-lengths of fair accuracy. The spectrum as measured by them consisted of a group of some 52 lines in the red extending from about 5600 to 7800 A and a group of about 30 lines in the violet. They used ordinary discharge tubes at reduced pressures and a spark discharge at atmospheric pressure. The violet lines were observed to come out only under the conditions of the spark discharge. A group of bands extending from the green into the red and degraded to the red was also observed and the approximate wave-lengths of the heads were given.

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[1] *Die Spectrum der Elemente bei Normalen Druck*, **3**, 85.

[2] *Gazetta Chimica Italiana*, **42b**, 42, 1912.

[3] *Astrophysical Journal*, **54**, 133, 1921.

[4] *Ibid.*, **59**, 125, 1924.

The question of the analysis of this spectrum was of course a matter of importance for the assignment of the lines to their proper spectrum series and the determination of the term combinations would indicate the form of ionization existing in the atom. A powerful method for this analysis lay in the study of the anomalous Zeeman patterns, which were obtained as described below.

APPARATUS

MAGNET

When the work was proposed no electromagnet of sufficient size was available, therefore a design was made and the construction undertaken in the laboratory shop. The magnet is of the Weiss type. The U-shaped yoke, the pattern for which was very kindly loaned by Mr. S. J. Barnett, then of the Carnegie Institution of Washington, is made of a special grade of low carbon cast steel to prevent as far as possible any effect of residual magnetism when the current is removed.

The cores are 4 inches in diameter, are made of Swedish iron, and can be adjusted for various pole gaps to 1/100 of a mm by calibrated hand wheels. They are drilled their whole length to accommodate heavy 1.25-inch bolts which are provided with small hand wheels and are used to clamp on any desired form of pole piece.

The bobbins are formed of brass plates and tubing and are wound with 4065 turns of No. 12 Deltasbeston wire calculated to stand high temperatures. Each bobbin is provided with four cooling coils of 1/4-inch copper tubing through which water can be circulated. One coil is placed on the core of the bobbin, one on each of the face plates, and one through the center of the winding parallel to the core coil. The end connections are brought out to two manifolds constructed of 1/2-inch nickel-plated pipe equipped with hose connections and mounted on the side of the yoke. These coils, together with the fact that the asbestos insulation allows the winding to run quite hot, enable the magnet to operate much longer at higher field-strengths than are permissible in the ordinary magnet wound with wire.

The combined resistance of the windings in parallel is 4.07 ohms. Additional taps are brought out from the center of each winding and 1858 turns with a combined resistance in parallel of 1.38 ohms can be used on battery circuits whenever a very steady field is desired. The heavy binding posts are set on a bakelite strip mounted directly on the coils to prevent any possibility of the wire taps being broken off where they come out of the winding. The winding is insulated from the cooling coils by sheets of mica.

The whole is placed on a ball thrust bearing mounted in a heavy tripod equipped with a clamping screw and three leveling screws. A horizontal scale calibrated to degrees permits the magnet to be set at any desired angle. This arrangement is convenient for certain types of work. The total weight of the assembled magnet is about 700 pounds.

Heat runs have indicated that the magnet can be operated at 30,000 ampere turns indefinitely, at 40,000 ampere turns for periods of 5 to 6 hours, and at 60,000 ampere turns for an hour or so without seriously overheating the windings.

The field-strength has not been measured except for the setting used for the experimental work. Under these conditions the pole-pieces were turned conical to a double angle of 114°. The tips were made 1 cm in diameter and a pole gap of 8 mm was used. Table I gives an idea of the performance of the magnet under these conditions.

TABLE I

Ampere Turns	Field Strength in Gausses
40,000	27,000
30,000	26,200
20,000	23,800
10,000	15,500
5,000	8,000

The magnet was calibrated by obtaining the Zeeman patterns of the *Zn* triplet 4680.20, 4722.16, 4810.53. A condensed discharge driven by a 3/4 K.W. Thordarsen transformer between *Zn* terminals was used as a source and gave very good patterns when enough inductance was used in the spark circuit to sharpen the lines. It was found that, if copper was used for one of the electrodes, the *Zn* electrode wore down more evenly under the discharge than when both were made of zinc, and did not require such frequent renewals. A five-minute exposure in the second order of a 10-inch grating, 30-foot Littrow mounting, gave very good patterns.

All three zinc lines give total separations of double the "normal" triplet interval and separations which are proportional to the field-strength as has been shown by Cotton and Weiss[1] and others. The separations of the outer components, $d\lambda$, of the three lines were measured and the field deduced by means of the following formula:

$$H=\frac{d\lambda}{\lambda^2 a}\quad (a=1.875\times 10^{-4}\text{cm}^{-1}\text{ Gauss}^{-1}).$$

The mean of the three determinations was taken as the value of the field. Determinations were made not only at the current-strength used in the fluorine exposures, but also at various other current-strengths, and a calibration-curve was obtained. In order to determine whether the calibration had changed during the course of the tests due to a possible short-circuiting of some of the turns or to the use of the magnet, a recalibration was made after the experiments were completed and was found to be identical with the initial calibration within the limits of observational error.

The procedure during the tests was to carefully demagnetize the magnet before each exposure by repeated reversals of the current and a gradual lowering of its value to zero. The current was then brought up to the full value and the magnet allowed to come to a stable condition before starting the test. Adjustments of the current were made by control rheostats. The same ammeter was used throughout the work. The actual field-strength used on all of the exposures was 24,590 gausses.

DISCHARGE TUBE

It was early found that the ordinary form of discharge tube placed perpendicular to the field was out of the question. As has been observed elsewhere, it is not very satisfactory under the best of conditions owing in the first place to the fact that the field-strength is necessarily lowered by the requirement of wedge-shaped pole pieces. Moreover, the field flattens the discharge against the walls of the capillary, weakens the spot of light, and introduces effects of pressure and temperature. These conditions, together with the fact that high electrostatic fields are required to maintain the discharge,

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[1] *Journal de Physique*, **6**, 429, 1907.

make it difficult to obtain fine lines. With the use of fluorine an additional difficulty arose from the fact that the flattened discharge caused the glass of the capillary to be attacked very rapidly and the tubes would not last over thirty minutes even with weak fields.

Attempts were made to use a spark discharge in an atmosphere of fluorine gas at reduced and atmospheric pressures, but the condensed transformer discharge required to give the desired brilliancy produced diffuse lines.

A 600-volt D.C. arc between tungsten terminals was then attempted, the arc being struck by the use of a heated filament. The tungsten, however, was attacked so rapidly by the fluorine that it would suddenly start to glow as though it were heated, giving a dirty white compound that settled all over the tube. Copper electrodes were tried, the arc being struck by setting up ionization with the secondary of a small transformer placed in series with the circuit and short-circuited when the arc started. It was found possible to excite the band spectrum by this method, but not the line spectrum.

An ordinary transformer discharge parallel to the field was then tried and under certain conditions was found to be very satisfactory. At low pressures of 4 or 5 mm of mercury, the discharge consisted of the ordinary diffuse glow that fills the bulbs of a common low-pressure discharge tube. The field had a tendency to restrict this to the neighborhood of the pole tips, but increased its intensity very little, if any. On raising the pressure, however, to 2 or 3 cm for fluorine—less for air—the discharge would suddenly become concentrated into a brilliant line similar in appearance to that obtained in the capillary of a discharge tube. This source was not only brilliant, but was calculated to give fine lines, for it took place in a small region of the field, the discharge being no more than a millimeter or so in breadth. Moreover, it took place under none of the bad conditions that beset the use of an ordinary discharge tube.

The discharge was stimulated by an ordinary 2200-volt lighting transformer run at about 750 volts with a current of about 150 milliamperes. The line spectrum only was observed to come out. The use of a small 3/4 K.W., 10,000-volt Thordarsen transformer, however, had a tendency to bring out the bands, also, but could not be used for any length of time owing to the overheating of the windings. It would appear from this and also from conditions of discharge in an ordinary discharge tube that the bands are best stimulated with low current-densities.

The final form of tube employed, which is somewhat similar to that used by Back with the vacuum-arc, is illustrated in the accompanying diagram. It was constructed of brass tubing three inches in diameter and mounted on shoulders recessed into the pole-pieces. A rubber gasket was used at the joint, which was shellacked over on the outside.

The electrodes were removable and when placed in the tube were slipped into metallic holders insulated from the tube by hard rubber sleeves. A collar on the electrode was tightened against the holder by a large thumb-nut. A rubber washer was used at the joint making it gas-tight. The hard rubber sleeves were attacked at first by the fluorine, but the action did not seem to spread after they had become covered with fluorine compounds. It was found necessary to cool with water the electrode holders.

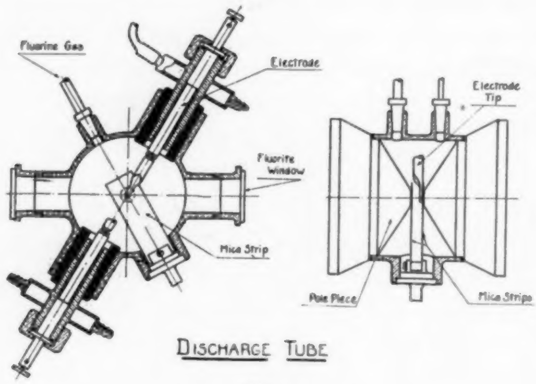

FIG. 1

The tips of the electrodes were removable and were fashioned out of copper, the actual discharge points being about 3 mm wide and 2 mm thick. It was found most feasible to use copper, as it is attacked relatively slowly by fluorine. Under the best conditions, however, it was impossible to run the discharge more than 7 to 10 hours without replacing the tips. These were set against the pole-pieces on either side of the gap, giving a discharge distance parallel to the field of about 3 mm. A jig, which duplicated the exact arrangement of the pole tip and electrode holder, was constructed in order that the tips of the electrodes could be accurately adjusted so as to come to the center of the pole-piece and to give the proper distance of discharge when slipped into the tube.

The electrodes were insulated from the pole-pieces by strips of mica. This detail proved troublesome at first, for the action of the fluorine under the heat of the discharge would quickly eat a hole in the mica and the discharge would short circuit to the pole-pieces. It was found that a small piece of copper foil about 1 cm in diameter, placed between two strips of mica, so as to come directly over the discharge point of the electrode, would prevent the corrosion from spreading through the mica strip next to the pole-piece. At the same time the electrode would remain insulated from the copper foil, except for the small area near the discharge point, which was not enough to influence the form of discharge. This proved the best of any device tried and would last as long as the electrode tip.

When new electrode tips were inserted, however, it was found best to put in new insulators. In order to do this easily the strips were mounted on a plug inserted in the bottom of the tube, the joint being sealed with soft wax. After a little warming of this joint, the plug could readily be removed.

Fluorite windows were used and it was found necessary to construct them so that they could easily be removed and cleaned. They were consequently mounted on metallic holders which were set on the tube with a lap-joint that was sealed with soft wax. This arrangement permitted the removal of the windows without heating the seal between the fluorite and the metal. This seal was made fluorine proof by using a thin film of a paste made of CaF and alcohol between the fluorite and the metal, with a final sealing of hard wax.

It was very important to arrange the tube in order that the windows, the mica insulators, and the electrodes could be quickly and easily renewed. It was often necessary to do this two or three times during a single exposure and to have to dismantle the whole tube would have been quite out of question. Finally the whole tube and the pole-pieces were given a heavy copper plating, which prevented as much as possible any action of the fluorine.

FLUORINE GENERATOR

The fluorine was generated as before in this laboratory by the electrolysis of dry KHF_2 fused at a temperature of about 250° C. The generator used by Smythe and by Gale and Monk was also used for this work. No essential change was made in any detail other than the replacement of the packed joint around the anode by an ordinary spark plug, the center electrode of which made contact with the anode by means of a flexible connection. This effectually prevented leaks from the top of the generator. Copper tubing was used to conduct the gas to the tube and from the tube to the Hyvac pump, which circulated the gas constantly throughout an exposure. A suitable regulation of the flow of the gas was effected by means of a brass needle-valve. With these arrangements the generating system required little attention over a series of several exposures.

PHOTOGRAPHY

The spectrograph, which was used for all of the exposures, was of the Littrow type with a focal length of 30 feet. The 10-inch Michelson grating (11,853 lines per inch) was employed. The dispersion of this instrument in the red is for the first, second, and fourth orders about 2.33, 1.12, and 0.47 A per mm, respectively. A slit width of 0.07 mm gave lines of very good definition.

A double-image prism placed over the window of the discharge tube gave two images of the source on the slit, one containing the light polarized in the direction of the field, and the other that polarized perpendicular to the field. This arrangement effected a complete analysis of the pattern with one exposure. The source was focused on the slit with a simple lens giving a five-fold magnification of the image.

In order to prevent any effect of the slit and rulings of the grating on the relative intensities of the components of different polarizations, a thin quartz plate was put over the slit so as to place all of the polarized components at 45° with the slit and the rulings of the grating. That such an effect existed in the instrument was shown by pictures of the zinc patterns taken with and without the use of the quartz plate.

Exposures of from eight to sixteen hours were made in the first, second, and fourth orders. These long exposures were necessary, for several of the lines gave Zeeman patterns having from 10 to 18 components. Iron comparison spectra were placed on all of the plates. Panchromatic plates bathed in dicyanin were used throughout. Photographs of the red spectrum only were made. It is uncertain whether the violet lines come out in this form of discharge. The lines that did appear in the violet seemed for various reasons to be attributable to copper, although no analysis was made.

RESULTS

The results have been reduced to the Landé system of classification, a condensed account of which for first-order spectra is given below.

According to this system we can specify our spectral terms by n^r_{kj} where n is the total quantum number, r the "permanent" term multiplicity (1, 2, 3, ... for singlets, doublets, triplets, etc.), k is the azimuthal quantum number (1, 2, 3, ... for the s, p, d terms, etc.) and j is the inner quantum number assigned arbitrary unique integral values for both odd and even multiplet systems on the basis of a selection principle.

All term-combinations are governed by the following principles of selection:

$$\Delta r = \pm 2,\ \Delta k = \pm 1,\ \Delta j = 0 \text{ or } \pm 1;\ j=0 \text{ to } j=0 \text{ being forbidden.}$$

In a magnetic field each term splits up in the case of even-numbered multiplet systems into $2j$ equidistant components and in the case of odd-numbered systems $2j+1$ equidistant components. The displacement of these components from the position of the original line is given in wave-numbers by

$$\Delta\nu = mg\Delta\nu_n$$

where $\Delta\nu_n$ is the "normal" triplet separation equal to $\frac{eH}{m4\pi c}$ and m is the magnetic quantum number which takes the values

$$m = \pm j-\tfrac{1}{2},\ j-\tfrac{3}{2},\ j-\tfrac{5}{2}\ \ldots\ldots \text{ for even systems}$$

$$m = \pm j,\ j-1,\ j-2,\ \ldots\ldots\ 0 \text{ for odd systems.}$$

The symbol g stands for the Landé "splitting" factor and is given by the following formula:

$$g=\tfrac{3}{2}+\frac{R^2-K^2}{2(J^2-\frac{1}{4})}$$

$R=r/2$; in terms of the atomic model, the angular momentum of the atomic residue

$K=k-\frac{1}{2}$; the angular momentum of the valence electron

$J=j$ for even systems; the vector sum of K and R

$J=j+\frac{1}{2}$ for odd systems

The combination of these magnetic energy-levels which gives the observed Zeeman patterns is governed by the following selection and polarization law:

$m-m'=0$; gives the (π) components polarized parallel to the field.

$m-m'=\pm 1$; gives the (σ) components polarized perpendicular to the field.

The transition $m=0$ to $m'=0$ is forbidden.

An intensity law states that where we have a combination of two term-levels having different numbers of mg components the most intense (π) component is that due to the transition between the low mg levels; and the most intense (σ) component is that due to the transition between the high mg levels. Where the number of mg components in the two terms is identical this rule is reversed, and the transition $mg=0$ to $m'g'=0$ is forbidden.

It is seen, then, that every combination of two terms having their own array of magnetic energy-levels gives a unique Zeeman pattern. Hence if the patterns can be obtained by photographic methods or otherwise, the identity of the spectral line with its place in the series and multiplet structure systems can be determined.

The actual determination of a pattern from the measurements on a plate can be best illustrated by considering the line 7311.40 which gives 6 components, 2 (π) components and 4 (σ) components. The most accurate method of reduction was to measure the interval between homologous components on either side of the center of the pattern. This separation was then halved and its fractional part of the "normal" Lorentz separation determined. From a consideration of these values for the various components the Runge numerators and denominators could be determined. Thus for 7311.40 we have

$$\frac{\Delta\ (\sigma_1)}{\Delta\ \text{normal}}=1.646,\ (23/20=1.650)$$

$$\frac{\Delta\ (\sigma_2)}{\Delta\ \text{normal}}=1.057,\ (21/20=1.050)$$

$$\frac{\Delta\ (\pi_1)}{\Delta\ \text{normal}}=0.295,\ (6/20=0.300).$$

The Zeeman type is then written

$$\frac{(6),\ \mathbf{21},\ 33}{20}$$

the bracket enclosing the (π) components and the bold-face figures indicating those components of greatest intensity. Obviously, plus and minus is understood before the type form, as the pattern is symmetrical.

Having determined the type, it was merely necessary to refer to the Zeeman patterns for the term combinations of various multiplet systems in order to complete the analysis. Out of some 30 lines that were observed by a direct-vision spectroscope, 20 have been analyzed and the term combinations of others proposed. The results are given in the appended table. The Zeeman patterns marked with an asterisk are to be considered uncertain, because their faintness made impossible an accurate analysis of the number and intervals of the components. The line 7332.25 gave a diffuse triplet, indicating unresolved components. A measurement, however, of the edges of the (π) and (σ) component groups could be made.

Ten of the lines have been found to give Zeeman patterns corresponding to the lines of the principal and diffuse series of the quartet system. This system gives a triplet term for the principal and sharp series and an eight-member term for the diffuse series.

TABLE II

λ	Int.	Term Combinations	Zeeman Types
6239.63	30.....	$ns^4 - mp^4_1$	$\frac{\mathbf{(1)}\ (3)\ \mathbf{5},\ 7,\ 9,\ 11}{5}$
6348.46	28.....	$ns^4 - mp^4_2$	$\frac{(2)\ \mathbf{(6)}\ 24,\ \mathbf{28},\ 32}{15}$
6413.61	23.....	$ns^4 - mp^4_3$	$\frac{(1)\ \mathbf{5},\ 7}{3}$
6569.66	1.....	$W - mp_1$	
6690.48	5.....	$W - mp_2$	
6762.91	6.....	$W - mp_3$	
6708.36	1.....	$np^4_1 - md^4_3$	
6773.96	20.....	$np^4_1 - md^4_2$	$\frac{(4)\ (12)\ \mathbf{(20)}\ 36,\ 44,\ \mathbf{52},\ 60,\ 68}{35}$
6795.47	3.....	$np^4_2 - md^4_4$	$\frac{(13)\ 13,\ \mathbf{39}}{15}$
6834.25	18.....	$np^4_2 - md^4_3$	$\frac{(4)\ \mathbf{(12)}\ 14,\ \mathbf{22},\ 30}{15}$
6856.01	40.....	$np^4_1 - md^4_1$	$\frac{\mathbf{(3)}\ (9)\ (15)\ \mathbf{35},\ 41,\ 47,\ 53,\ 59,\ 65}{35}$
6870.21	18.....	$np^4_3 - md^4_4$	$\frac{(4)\ 4}{3}$
6902.46	30.....	$np^4_2 - md^4_2$	$\frac{\mathbf{(19)}\ (57)\ \mathbf{87},\ 125,\ 163,\ 201}{105}$
6909.79	20.....	$np^4_3 - md^4_3$	$\frac{(11)\ \mathbf{7},\ 29}{15}$
6966.33	4.....	$X - md_3$	$\frac{(1)\ 3,\ \mathbf{5}^{*}}{3}$
7037.48	50.....	$X - md_2$	$\frac{(0)\ 4}{3}$
7128.36	5.....		$\frac{(0)\ 3}{4}$
7202.34	15.....		$\frac{(1)\ 3,\ \mathbf{5}}{3}$
7311.40	15.....	$mp_3 - Y$	$\frac{(6)\ \mathbf{21},\ 3^3}{20}$
7332.25	18.....	$Z - mp_1$	$\frac{(-,5)\ \mathbf{27},\ -^{*}}{20}$

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* Those term combinations showing terms of unknown identity such as *X*, *Y*, *Z*, etc., were deduced from a consideration of the wave-number intervals.

TABLE II—*Continued*

λ	Int.	Term Combinations	Zeeman Types
7398.96	20.....	mp_2–Y	$\frac{(0)\ 5}{3}$
7426.2	12.....		$\frac{(5)\ 13,\ 2^3}{10}$
7482.95	5.....	Z–mp_2	
7552.20	5.....	mp_1–Y	$\frac{(0)\ 3^*}{2}$
7573.32	5.....	Z–mp_3	$\frac{(10)\ 27^*}{20}$

* Those term combinations showing terms of unknown identity such as X, Y, Z, etc., were deduced from a consideration of the wave-number intervals.

That the sp_i lines belong to the principal series rather than to the sharp—the patterns being identical for both—is indicated by the fact that the transition between the s and p_1 levels gives the shortest wave-length and also the most intense of the group of three lines, which is usually the case, although not without exception.

Of the eight p_id_j lines the Zeeman patterns of all have been observed with the exception of p_1d_3, the identity of which, however, has been determined by the use of the intervals between the d levels.

These intervals between the various p levels and d levels have been deduced in terms of their mean differences of wave-number from the observed term combinations and are given below:

Δp_{12}..........	274.8
Δp_{23}..........	160.0
Δd_{12}..........	176.7
Δd_{23}..........	144.5
Δd_{34}..........	83.5

Gale and Monk, in their published list of wave-lengths, give no line that can be taken for p_1d_3. They have observed a line, however, at 6708.36, which they did not publish owing to an uncertainty regarding the impurities in the spectrum. It is of low intensity as the p_1d_3 line should be and a comparison of its wave-number with that of the line p_1d_2 (6773.96) gives Δd_{23} equal to 144.4, in strict accord with the value obtained from the consideration of other observed lines of the group. We may say, then, that 6708.36 is the p_1d_3 line of the diffuse series term.

The relative intensities of the lines appeared to vary according to the values assigned by Gale and Monk, with one outstanding exception in the case of the line 6569.66. This is given an intensity value of 10 by them, but was barely discernible with a direct-vision spectroscope in the form of discharge used. An examination of the intensity variations of the sp_i and p_id_j lines will show that they follow the order that would be expected.

It is to be observed, also, that the approximate law for the interval ratios between neighboring terms is confirmed here. This law states that the ratio of the term intervals varies as $\frac{1}{2}(J^2-J_1^2)$. For an even-numbered multiplet system we would expect then the ratios 3:5:7, etc. Actually, we observe for the d levels

$$\Delta d_{43}:\Delta d_{32}:\Delta d_{21}=3.0:5.19:6.35$$

and for the p levels

$$\Delta p_{32}:\Delta p_{21}=3.0:5.15\,.$$

The usefulness of this rule for predicting the multiplet structure of a given spectrum is well illustrated by a communication recently received by Professor Henry G. Gale from T. L. de Bruin at Amsterdam. He pointed out the existence of groups of lines in the fluorine spectrum giving constant frequency differences and deduced from the 3 to 5 interval ratio of these differences a quartet system.

The frequency intervals as found by him were the 160.0 and 274.8 intervals which appear from the above analysis to be the differences between the p levels. A partial analysis of some of the remaining lines of the spectrum has been obtained by considering the occurrence between these lines of wave-number intervals equal to those between the p levels and also the d levels. The X, Y, Z, etc., as given in the table, refer, of course, to unknown terms. Attention should be called to the rather large values of the *p* and *d* intervals as compared to those found in other elements of this part of the periodic table.

The fact that the Zeeman patterns of the remaining lines do not appear to belong to any of the first-order multiplet systems from singlets to octets might suggest a higher order spectrum. The analysis as given above on the basis of a first-order quartet system would, however, discourage this point of view. Moreover, a consideration of the Bohr orbits, while speculative, would not lead one to suppose the existence in the atomic residue of any orbits with *k* greater than 1 that would contribute to its angular momentum—the criterion for spectra of higher order.

The existence of the fluorine ion is suggested by the occurrence of several triplet patterns which are common to the odd-numbered multiplet systems found in the even-numbered columns of the periodic table. This is hardly to be expected, however, from a consideration of the strong electronegative character of fluorine and the type of discharge used. It might be said that, if we were to look for the existence of the negative ion, it would be in fluorine. The magnetic field appeared to have no effect on the general character of the spectrum.

Attention should be called to the line λ 7128.36 which came out quite strongly. This has been observed by Gale and Monk, although not included in their published list of wave-lengths as it appeared on only one of their plates. The presence of poorly defined Zeeman patterns on either side of the pattern of the line 7311.40 also indicated two close satellites at 7309.28 and 7314.52. These have also been observed by Gale and Monk but were not published owing to uncertainties as to their identity.

In conclusion the author wishes to express his thanks and appreciation to Professor Henry G. Gale under whose direction the work was done, to Dr. George S. Monk for his ready and valuable assistance in projecting the work and the analysis, and to Dr. F. C. Hoyt for valuable suggestions in the analysis.

RYERSON PHYSICAL LABORATORY

REDUCTION OF THIRTY-NINE ASTROGRAPHIC ZONES TO THE INTERNATIONAL PHOTOGRAPHIC SCALE[1]

By FREDERICK H. SEARES and MARY C. JOYNER

ABSTRACT

Calibration of magnitude scales of thirty-nine astrographic zones.—Photographic magnitudes on the international scale corresponding to the values of log N_m (N_m = number of stars per square degree brighter than m) given for thirty-three zones in Table XV, *Mt. Wilson Contr.* No. 301, were interpolated from Table XVII of that paper. Together with the equivalent scale-readings or provisional magnitudes used to express the brightness of the stars, the interpolated magnitudes provide a calibration for from three to five points on the scales of the individual zones. The calibration was extended to other scale-readings for which counts are available by comparing mean densities for entire zones to successive limits of scale-reading with the adopted mean distribution of stars for all latitudes together. *Final results* are in Table IV, which also includes data for six Oxford zones for which counts have recently been published. Although the calibrations refer to zones as a whole, the residuals in limiting magnitude for different galactic latitudes given in Table I indicate that in many cases the calibrations are directly applicable to small parts of a zone. These residuals are not, however, a final test of consistency in the scales, because both errors of reduction and irregularities in stellar distribution contribute to their progressive character.

The determination of stellar distribution given in *Contribution* No. 301[2] was based in part on counts of thirty-three zones of the *Astrographic Catalogue*, collected and published mostly by Turner.[3] These data were referred to the international photographic scale by comparing values of log N_m (N_m = number of stars per square degree brighter than m) derived from the counts in each zone with van Rhijn's distribution table[4] which had already been reduced to the international scale by comparison with the *Mount Wilson Catalogue.* Mean densities (log N_m) for galactic latitudes 0°, 10°, 20° . . . . corresponding to several limiting values of the scale-reading[5] in each zone,

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[1] *Contributions from Mt. Wilson Observatory*, No. 305.

[2] *Astrophysical Journal*, **62**, 320, 1925.

[3] *Ibid.*, Table XIII gives references to the published data.

[4] *Groningen Publication*, No. 27, Table IV, 1917.

[5] The term "scale-reading" is used to indicate the brightness of stars as expressed in the zones, irrespective of whether the quantities given are actual scale-readings, estimates of brightness, or provisional magnitudes.

and the means of the equivalent magnitudes interpolated from van Rhijn's table, may be found in Table XV of *Contribution* No. 301.

The mean magnitudes and the corresponding scale-readings, which were not given in Table XV, provide a calibration of the scales of the astrographic zones in terms of the international photographic scale. although not the best possible because of the influence of residual errors in van Rhijn's table. As remarked in *Contribution* No. 301, the precision can be increased by a reinterpolation of the magnitudes from the adopted distribution table. The details of this revision are shown in Table I of this article, arranged according to the declination of the zones. These results are later subjected to a process which minimizes the influence of certain accidental errors, and, finally, extended to scale-readings for which corresponding magnitudes have not yet been calculated. The adopted calibration is in Table IV, which gives the mean photographic magnitude on the international scale for practically all scale-readings for which counts are available. The omissions relate to bright stars in a few zones which are not numerous enough to give reliable values of the magnitudes.

The results of the reinterpolation are in the second and third lines from the end of each division of Table I. Thus for the Vatican zones,[1] +62°, scale-readings 40, 30, ... 0 correspond, respectively, to revised magnitudes 8.87, 10.08, ... 12.98. The provisional magnitudes from Table XV, *Contribution* No. 301, which head the columns of Table I, identify the mean densities used for the reinterpolation. For example, the densities corresponding to scale-reading 40 in the Vatican zones stand opposite provisional magnitude 8.81 in the fourth line of Table XV, *Contribution* No. 301. With the aid of Table XVII of that paper these densities give the revised magnitudes 9.26, 9.14, ... 8.62, which deviate from their mean of 8.87 by the amounts shown in Table I opposite the latitudes to which they refer. Occasionally the same provisional magnitude is associated with more than one series of densities; the declination of the zone, which also appears in Table XV, then removes the ambiguity.

[1] The published counts are the means for the three zones in declinations +64°, +62°, and +60°.

TABLE I

PROVISIONAL MAGNITUDES AND DEVIATIONS

LAT.	VATICAN +62°					OXFORD +31°				
	8.81	10.04	11.10	12.32	12.97	....	....	....	....	....
0°..............	−39	−13	− 4	0	+ 1	+20	+18	+18	+35	+34
10..............	−27	−11	− 1	0	− 1	+15	+13	+10	+22	+22
20..............	−10	− 5	−11	−14	−10	+ 8	+ 6	+ 4	+14	+13
30..............	+12	+ 6	− 3	−10	− 3	+ 7	+ 8	+ 5	+15	+14
40..............	+17	+ 4	− 2	− 1	+ 4	0	+ 4	+ 8	+ 9	+10
50..............	+21	+ 7	+ 6	+10	+ 6	− 6	− 2	+ 4	0	+ 7
60..............	+25	+10	+12	+12	+ 3	− 7	−10	− 4	−15	−13
70..............	....	....	....	....	....	−10	−15	−13	−28	−25
80..............	....	....	....	....	....	− 9	−14	−19	−26	−30
90..............	....	....	....	....	....	−14	−13	−15	−26	−31
Rev. *m*..........	8.87	10.08	11.15	12.35	12.98	9.59	10.72	11.89	12.89	13.48
Sc.R..............	40	30	20	10	0	35	26	18	12	All
m−*m*′..........	−0.39	−0.23	−0.22	−0.22	−0.22	+0.01	+0.12	+0.09	+0.10	+0.10

LAT.	OXFORD +30°					OXFORD +29°				
	....	....	....	....	....	....	....	....	....	....
0°..............	+28	+22	+22	+36	+20	+29	+34	+33	+41	+29
10..............	+17	+ 9	+ 6	+18	+ 9	+17	+23	+24	+30	+14
20..............	+11	− 5	− 5	+ 2	− 2	+ 4	+ 6	+ 9	+15	+10
30..............	+ 8	− 6	− 3	− 1	+ 3	− 2	0	+ 2	+ 7	+10
40..............	+ 1	− 7	+ 2	− 2	+ 3	−11	−10	− 8	+ 2	+ 5
50..............	− 3	− 6	+ 3	− 3	+ 2	− 5	− 8	−13	− 3	− 1
60..............	− 7	− 5	0	− 9	− 4	− 8	−10	−18	−11	−10
70..............	−15	− 2	−10	−13	− 9	−10	−12	−13	−20	−18
80..............	−18	− 1	− 8	−14	−11	−10	−12	−12	−26	−16
90..............	−22	0	− 7	−14	−12	− 9	−14	− 9	−30	−20
Rev. *m*..........	9.76	10.85	12.09	12.92	13.70	9.36	10.28	11.50	12.52	13.55
Sc.R..............	35	26	18	12	All	35	26	18	12	All
m−*m*′..........	−0.03	+0.03	+0.13	+0.07	+0.10	−0.01	0.00	+0.07	+0.18	+0.19

LAT.	OXFORD +28°			OXFORD +27°				
	10.05	12.43	13.68	....	....	....	....	....
0°..............	+17	+12	+ 9	+ 8	+23	+25	+24	+26
10..............	+16	0	− 2	+ 6	+11	+19	+15	+12
20..............	− 2	+ 5	+ 1	− 1	− 1	+ 9	+ 3	− 1
30..............	+ 5	+19	+23	+ 3	+ 3	+ 9	+ 3	0
40..............	0	+10	+12	+ 6	+ 5	+ 7	+ 5	+ 9
50..............	− 2	− 3	0	+ 3	+ 6	− 2	+ 5	+13
60..............	− 6	−14	−15	− 2	+ 2	− 8	− 1	0
70..............	−15	−28	−30	− 6	− 7	−19	−15	−14
80..............	....	....	....	−11	−18	−22	−20	−21
90..............	....	....	....	−10	−23	−21	−23	−25
Rev. *m*..........	10.04	12.44	13.62	9.20	10.12	11.35	12.25	13.28
Sc.R..............	30	12	All	35	26	18	12	All
m−*m*′..........	+0.15	+0.24	+0.22	+0.07	+0.07	+0.12	+0.17	+0.15

LAT.	OXFORD +26°					OXFORD +25°				
	....	....	....	....	....	....	....	....	....	....
0°..............	+ 4	+ 9	+13	+17	+29	+32	+23	+29	+19	+24
10..............	+ 3	+ 2	+ 6	+ 5	+ 9	+20	+16	+14	+ 4	+ 7
20..............	0	− 6	0	+ 5	− 8	+ 7	+10	− 2	−10	− 5
30..............	+ 2	+ 5	+10	+11	− 2	+ 4	+11	− 6	− 4	+ 3
40..............	+ 1	+12	+18	+18	+10	+ 2	+10	+ 3	+ 9	+12
50..............	+ 7	+12	+10	+15	+ 7	− 4	+ 2	+ 5	+15	+ 9
60..............	+ 5	+ 5	− 4	− 4	− 7	−10	− 9	− 3	+ 4	− 5
70..............	− 1	− 4	−13	−18	− 6	−16	−19	− 9	− 8	−14
80..............	− 7	−15	−21	−21	−14	−18	−23	−15	−14	−15
90..............	−12	−20	−24	−28	−18	−17	−22	−11	−12	−13
Rev. *m*..........	9.31	10.33	11.58	12.54	13.48	9.58	10.63	11.90	12.73	13.53
Sc.R..............	35	26	18	12	All	35	26	18	12	All
m−*m*′..........	+0.07	+0.08	+0.18	+0.18	+0.16	+0.15	+0.13	+0.18	+0.08	+0.17

TABLE I—*Continued*

LAT.	PARIS +23°					PARIS +22°				
	9.20	10.45	11.74	12.82	13.25	9.26	10.38	11.71	12.79	13.34
0°	+25	+32	+40	+32	−14	+25	+20	+26	+14	− 7
10	+21	+25	+20	+14	−25	+20	+15	+21	+ 8	−12
20	+11	+10	0	− 7	−29	+10	+10	+ 8	+ 5	− 8
30	+ 5	+ 9	− 9	−17	−21	+ 3	+ 4	+ 7	+ 8	−11
40	− 2	− 3	− 9	−10	− 3	− 3	+ 4	+ 5	+ 8	− 2
50	− 7	−11	−10	+ 3	+21	− 6	− 2	+ 2	+ 5	+ 4
60	− 9	−14	− 7	0	+23	− 9	− 9	− 9	− 7	+ 6
70	−15	−16	− 7	− 3	+19	−14	−16	−15	−13	+ 8
80	−14	−17	− 7	− 6	+15	−15	−14	−21	−13	+10
90	−13	−16	− 7	− 4	+12	−15	−11	−20	−14	+12
Rev. *m*	9.17	10.42	11.75	12.81	13.27	9.23	10.37	11.73	12.80	13.34
Sc.R.	8.0	9.0	10.0	11.0	All	8.0	9.0	10.0	11.0	All
m−*m*′	+0.13	+0.17	+0.19	+0.16	0.00	+0.21	+0.21	+0.27	+0.23	+0.04

LAT.	BORDEAUX +17°			BORDEAUX +16°				
	10.76	12.35	13.18	8.66	10.06	11.46	12.24	12.75
0°	+32	+21	+14	+20	+13	+ 5	+ 4	−2
10	+17	+ 9	+ 5	+16	+ 9	+10	+ 5	0
20	− 1	− 5	0	+ 9	+ 7	+ 9	+ 3	+6
30	− 5	+ 2	+ 4	+ 8	+ 8	+ 9	+ 8	+6
40	− 8	0	+11	− 6	− 2	+ 2	+ 7	+6
50	− 7	+ 1	+ 4	−10	− 6	− 3	+ 2	+3
60	− 8	− 6	− 6	−12	− 8	− 7	− 5	−3
70	−10	− 8	−13	−14	−12	−10	−10	−6
80	− 9	−11	−21	−15	−12	−12	−13	−6
Rev. *m*	10.74	12.34	13.16	8.62	10.05	11.50	12.27	12.78
Sc.R.	8.5	10.0	12.0	7.5	8.5	9.5	10.5	12.5
m−*m*′	+0.29	+0.28	+0.28	+0.08	+0.05	+0.13	+0.10	+0.14

LAT.	BORDEAUX +15°				BORDEAUX +14°			
	9.66	11.23	12.15	12.66	9.99	11.43	12.43	12.92
0°	+2	0	+5	+8	−1	−21	−26	−42
10	+5	+2	+3	−1	−8	−17	−23	−30
20	−2	0	+1	−1	−4	−12	− 6	−12
30	−2	+5	+1	−6	+3	+ 4	+ 9	+ 9
40	−5	−2	−2	−3	+1	+ 5	+10	+13
50	−1	−6	+1	−1	+1	+ 5	+ 7	+15
60	0	−4	−2	0	+2	+ 7	+ 6	+12
70	+2	−1	−4	0	+2	+12	+ 9	+15
80	+3	+3	−1	0	+2	+18	+15	+17
Rev. *m*	9.66	11.26	12.18	12.66	10.00	11.50	12.49	12.99
Sc.R.	8.5	9.5	10.5	12.5	8.5	9.5	10.5	12.5
m−*m*′	+0.03	+0.09	+0.10	+0.12	+0.08	+0.02	+0.05	+0.03

LAT.	TOULOUSE +9°				ALGIERS −1°		
	8.92	10.28	11.38	12.55	9.21	11.39	12.94
0°	−49	−37	−26	−16	+ 4	−11	−21
10	−41	−31	−15	−17	− 1	−14	−23
20	−15	− 7	− 8	−11	− 7	−10	−16
30	+ 5	+ 9	+ 6	− 5	− 6	− 1	+ 2
40	+17	+19	+ 9	+ 1	− 4	+ 7	+12
50	+27	+19	+12	+12	+ 5	+13	+23
60	+27	+17	+12	+19	+10	+15	+20
70	+29	+13	+12	+17	....	....	....
Rev. *m*	8.99	10.35	11.47	12.59	9.20	11.45	12.98
Sc.R.	8.5	9.5	11.0	12.3	7.9	9.9	11.9
m−*m*′	−0.20	−0.01	+0.04	+0.08	+0.20	+0.21	+0.31

TABLE I—*Continued*

LAT.	SAN FERNANDO −3°				SAN FERNANDO −4°			
	10.16	11.62	12.74	13.27	10.00	11.43	12.59	13.04
0°	+17	+27	+15	+6	+22	+21	+ 8	0
10	+ 5	+10	+ 6	−1	+11	+17	+11	+ 5
20	− 7	− 3	+ 3	−4	− 3	+ 4	+16	+11
30	− 6	+ 1	+ 4	+5	−11	− 3	+15	+ 8
40	− 9	− 6	− 1	+6	−11	− 8	+ 7	+13
50	− 1	− 4	− 2	+1	− 1	− 5	− 7	+ 4
60	0	−11	− 8	−3	− 2	− 9	−18	−15
70	− 2	−18	−17	−8	− 8	−18	−30	−25
Rev. *m*	10.15	11.62	12.73	13.25	9.98	11.45	12.60	13.04
Sc.R.	8.5	9.5	10.5	All	8.5	9.5	10.5	All
$m-m'$	+0.16	+0.25	+0.24	+0.24	+0.25	+0.22	+0.29	+0.37

LAT.	SAN FERNANDO −5°				SAN FERNANDO −6°			
	10.02	11.41	12.51	13.06	10.04	11.33	12.28	12.87
0°	+26	+25	+19	+1	+19	+10	+ 9	+ 1
10	+12	+14	+18	−6	+ 8	+10	+14	+ 7
20	− 2	+ 1	+11	−3	− 4	+ 8	+15	+11
30	−10	− 4	+ 5	−2	+ 2	+ 5	+10	+ 6
40	− 8	−11	0	+3	+ 2	− 2	− 2	0
50	− 2	− 8	− 8	+7	− 5	− 7	−10	− 1
60	− 6	−10	−19	+1	− 9	−10	−17	− 7
70	−13	−10	−28	−3	−13	•−10	−22	−17
Rev. *m*	9.99	11.42	12.50	13.05	10.04	11.36	12.29	12.88
Sc.R.	8.5	9.5	10.5	All	8.5	9.5	10.5	All
$m-m'$	+0.22	+0.25	+0.28	+0.25	+0.25	+0.30	+0.28	+0.26

LAT.	TACUBAYA −15°				TACUBAYA −16°			
	10.03	11.27	12.47	13.27	9.94	11.29	12.45	13.23
0°	+22	+16	+13	− 4	+37	+26	− 6	−38
10	+15	+12	+11	− 8	+27	+20	− 1	− 9
20	+ 1	0	+ 6	− 6	+17	+13	+ 4	+ 3
30	0	+ 2	+ 3	0	+ 7	+11	+13	+15
40	− 5	0	+ 1	+ 4	− 2	+ 1	+17	+22
50	− 7	− 2	− 2	+11	−11	− 3	+15	+15
60	−11	−10	−10	+ 4	−20	−11	− 1	+ 5
70	−15	−18	−18	− 3	−27	−23	−15	− 6
80	....	....	....	....	−32	−31	−24	−10
Rev. *m*	10.02	11.28	12.48	13.26	9.90	11.29	12.48	13.27
Sc.R.	8.5	9.5	10.5	11.5	8.5	9.5	10.5	11.5
$m-m'$	+0.14	+0.13	+0.09	+0.10	+0.22	+0.24	+0.15	+0.13

LAT.	HYDERABAD −17°			HYDERABAD −18°				
	9.53	12.16	13.38	9.57	11.48	12.18	12.84	13.38
0°	+13	+13	+ 3	+24	+53	+30	+35	+ 8
10	+ 8	+17	+13	+28	+44	+45	+39	+28
20	+ 1	+15	+18	+19	+28	+45	+39	+34
30	+ 4	+11	+11	+ 4	+11	+23	+20	+17
40	0	+ 2	+ 4	− 5	− 6	− 1	− 2	+ 1
50	− 1	− 3	− 1	−13	−17	−20	−17	−13
60	− 4	− 9	− 9	−16	−29	−32	−29	−21
70	− 6	−17	−14	−20	−38	−40	−39	−26
80	−11	−26	−21	−20	−44	−46	−43	−31
Rev. *m*	9.52	12.17	13.34	9.54	11.44	12.17	12.81	13.34
Sc.R.	50	20	8	50	30	20	12	8
$m-m'$	+0.11	+0.30	+0.19	+0.09	+0.26	+0.28	+0.30	+0.25

TABLE I—*Continued*

Lat.	Hyderabad −19°					Cordoba −25°				
	9.39	10.19	11.35	12.19	13.30	8.74	9.95	11.33	12.88	13.36
0°	+36	+23	+38	+23	+12	+14	−14	−13	+14	+21
10	+24	+16	+27	+19	+7	+6	−12	−18	0	+11
20	+3	+4	+13	+19	+12	−6	−10	−16	−1	+5
30	−4	+3	+6	+10	+16	−8	−4	−4	+4	+4
40	−8	−2	−4	+1	+6	−8	−1	+6	−2	−1
50	−9	−4	−11	−3	+1	−5	+2	+7	−3	−1
60	−12	−7	−18	−16	−9	−2	+10	+9	−3	−8
70	−14	−15	−23	−23	−17	+2	+9	+9	−4	−10
80	−19	−19	−26	−26	−24	+2	+9	+7	−4	−14
90	......	......	......	......	......	+4	+10	+13	−5	−8
Rev. *m*	9.34	10.19	11.34	12.19	13.28	8.72	9.98	11.39	12.89	13.32
Sc.R.	50	40	30	20	8	41	31	21	11	1
m−*m′*	+0.17	+0.17	+0.16	+0.22	+0.22	+0.05	−0.02	0.00	+0.05	+0.08

Lat.	Cordoba −27°					Cordoba −29°			
	8.62	10.04	11.38	12.79	13.03	9.25	10.70	12.48	12.96
0°	0	−12	−12	−9	−10	−21	−29	−6	−8
10	−9	−19	−15	−13	−18	−18	−21	+1	−7
20	−17	−13	−2	+3	+3	−10	−8	−2	−4
30	0	+10	+23	+11	+16	−9	−7	−3	+1
40	+3	+10	+16	+11	+18	−9	−6	−5	0
50	+6	+11	+12	+16	+14	+3	−2	−3	+4
60	+9	+12	+1	+5	+5	+12	+7	+4	+7
70	+6	+5	−5	−4	−5	+18	+16	+5	+3
80	+2	+1	−7	−10	−12	+19	+22	+1	+3
90	+1	−2	−9	−14	−12	+19	+24	+5	+2
Rev. *m*	8.62	10.07	11.44	12.83	13.06	9.27	10.74	12.50	12.99
Sc.R.	41	31	21	11	1	31	21	11	1
m−*m′*	−0.01	−0.02	+0.03	+0.06	+0.08	−0.10	−0.11	−0.01	−0.01

Lat.	Cordoba −31°				Perth −32°		
	9.15	10.58	12.51	13.21	10.35	11.88	13.11
0°	−35	−32	−23	−8	−8	−24	−24
10	−22	−5	−7	−14	−9	−14	−15
20	+4	+8	+2	−18	−8	−11	−5
30	+26	+17	+12	+2	+6	+7	+7
40	+22	+16	+21	+17	+17	+17	+15
50	+15	+15	+15	+22	+15	+22	+22
60	+8	+5	+5	+12	+5	+14	+13
70	−1	−2	−6	−1	−6	+2	0
80	−8	−9	−9	−8	−15	−9	−10
90	−12	−11	−12	−9	......	......	......
Rev. *m*	9.18	10.61	12.57	13.22	10.36	11.96	13.14
Sc.R.	31	21	11	1	D	G	M
m−*m′*	−0.06	−0.18	−0.11	−0.02	−0.05	−0.11	−0.10

Lat.	Perth −34°					Perth −36°				
	8.84	10.12	11.38	12.51	13.19	9.38	10.62	11.76	12.76	13.53
0°	−41	−28	−28	−26	−32	−6	−4	0	+15	−1
10	−30	−18	−14	−13	−13	+7	−2	+16	+27	+23
20	−17	−13	−5	+1	+4	+12	+15	+18	+24	+20
30	−12	−2	−3	+3	−3	+16	+22	+17	+18	+21
40	−2	+2	−3	−2	−1	+8	+9	+9	+2	+11
50	+9	+10	+2	+1	+5	+2	+1	−2	−8	−1
60	+15	+11	+7	+4	+4	−6	−8	−13	−19	−16
70	+21	+10	+10	+5	+6	−13	−15	−19	−26	−24
80	+27	+12	+16	+11	+14	−18	−19	−25	−30	−29
90	+33	+18	+22	+14	+20	......	......	......	......	......
Rev. *m*	8.89	10.16	11.45	12.56	13.23	9.38	10.64	11.80	12.76	13.52
Sc.R.	B	D	F	H	M	B	D	F	H	M
m−*m′*	−0.21	−0.10	−0.09	−0.05	−0.07	+0.01	+0.06	+0.09	+0.10	+0.12

TABLE I—*Continued*

LAT.	PERTH-EDINBURGH −38°					CAPE −41°			
	9.32	10.04	11.33	12.89	13.56	10.75	11.66	12.85	13.48
0°	−10	− 7	− 5	+ 9	+ 2	+13	− 6	− 9	−11
10	− 3	+ 4	+11	+ 8	+11	+12	− 2	−11	− 9
20	+ 6	+ 9	+16	+ 6	+ 7	+11	− 5	−10	− 9
30	+17	+17	+14	+12	+ 7	+12	+ 4	− 2	+ 2
40	+ 6	+ 7	+ 2	+ 9	+ 2	+ 4	+11	+ 8	+11
50	0	+ 1	− 3	+ 3	+ 2	− 2	+11	+21	+14
60	− 2	− 6	− 6	− 9	− 6	− 8	+ 4	+13	+10
70	− 5	−12	−12	−16	−12	−18	− 5	− 2	− 1
80	− 9	−15	−17	−20	−16	−25	−10	−12	− 8
Rev. *m*	9.32	10.07	11.37	12.89	13.52	10.74	11.72	12.88	13.47
Sc.R.	40	30	20	10	All	130	100	−3	−5
$m-m'$	−0.05	−0.02	+0.07	+0.03	+0.03	−0.06	−0.17	−0.13	−0.07

LAT.	CAPE −42°				CAPE −43°			
	9.49	11.80	12.49	13.57	9.57	11.76	12.45	13.54
0°	+ 6	0	+ 2	+ 5	− 1	0	− 6	− 2
10	− 1	−13	− 6	−11	− 4	− 8	−16	−10
20	− 5	−22	−21	−30	−11	−20	−24	−23
30	−16	−19	−21	−25	− 5	−16	−16	−22
40	− 8	− 7	−13	−11	0	− 7	− 5	− 8
50	+ 2	+ 6	+ 4	+ 9	+ 6	+11	+11	+13
60	+ 7	+14	+11	+13	+ 6	+12	+19	+20
70	+ 9	+17	+17	+24	+ 5	+14	+20	+15
80	+ 7	+23	+26	+23	+ 6	+12	+20	+17
Rev. *m*	9.48	11.85	12.51	13.53	9.59	11.80	12.48	13.51
Sc.R.	200	100	60	−5	200	100	60	−5
$m-m'$	−0.11	−0.06	−0.08	−0.20	−0.07	−0.07	−0.03	−0.07

LAT.	MELBOURNE −65°					
	....	....	....	11.00	....	13.02
0°	−10	−17	− 1	−20	− 7	−18
10	−13	−19	−15	−20	−11	−25
20	−12	−15	− 8	− 6	− 6	−23
30	− 3	− 8	− 3	+ 5	+ 3	− 1
40	+ 4	+ 7	+ 2	+14	+ 3	+18
50	+15	+23	+11	+15	+11	+28
60	+18	+26	+15	+13	+ 5	+22
Rev. *m*	8.97	9.47	9.90	11.06	12.29	13.06
Sc.R.	31	26	21	16	11	All
$m-m'$	−0.30	−0.27	−0.32	−0.16	−0.21	−0.30

NOTES TO TABLE I

Oxford: Published limits for scale-readings of zones +31° to +29° and +27° to +25° increased one unit. *Monthly Notices*, **85**, 473.

Toulouse: For 0^h-6^h a scale of quarter-magnitudes was used, the record being to the nearest tenth; for 7^h-23^h, a scale of tenths, extending to 13.3. *Ibid.*, **76**, 149. Scale-readings below 12.3 have not been used. For the same scale-reading values of log N_m in the first quadrant are systematically lower than elsewhere by about 0.15. The corresponding values of m are about 0.35 mag. less than the tabulated limits, which refer to the interval 7^h-23^h.

Algiers: Published limits reduced 0.1. *Ibid.*, **72**, 701.

Cordoba: The diameters of 58 stars at −25° have not been measured, being too faint or too large. *Ibid.*, **78**, 58. The inference from the text is that these stars are not included in the totals. If so, the value of m for Sc.R. 51 (See Table IV) is appreciably affected—the other magnitude limits to a much less extent. For zones −27°, −29°, −31°, the published limits for scale-readings have been increased by one unit (*ibid.*, **81**, 528) and "All" is assumed to correspond to Sc.R. 1, as for −25°.

Cape: Scale-readings for zones −42° and −43° assigned in accordance with the identification in *ibid.*, **79**, 567.

Melbourne: Published limits for scale-reading increased by one unit. *Ibid.*, **77**, 39.

Values of log N_m for latitude 0° were not used in deriving provisional magnitudes because of the relatively large uncertainty affecting van Rhijn's distribution table in low latitudes. This objection does not hold in the case of the revised distribution table —at least not for the interval of brightness covered by the astrographic zones—and all available densities have accordingly been used. In general, the results of the reinterpolation are in close agreement with the provisional values found from van Rhijn's table. The largest difference is 0.09 mag.; the average, without regard to sign, 0.027; and the systematic difference, 0.01 mag.

Counts for six of the seven Oxford zones were published[1] after the reductions for *Contribution* No. 301 had been finished. Mean densities for these zones are collected in Table II, which also gives densities corresponding to four additional scale-readings of the Melbourne zone, $-65°$, necessary to complete the calibration. Provisional magnitudes were not derived, and the values in Table II are based on the revised distribution table.

The scale-readings in Table I, and indeed throughout the present discussion, are inclusive limiting values; the corresponding densities depend on counts which include all stars having a brightness equal to and greater than that represented by the scale-reading in question. This accounts for certain modifications of published values of the limits of the original counts referred to in the notes to Table I. The magnitudes therefore correspond to the faintest stars to which the respective scale-readings are assigned. Since the interval of brightness covered by the smallest step in scale-reading is sometimes half a magnitude or more, this point must be borne in mind in using the adopted calibration in Table IV.

The residuals in Table I are generally systematic, usually most noticeably so in the case of the brighter stars. This indicates a systematic departure, depending on latitude, of the mean zone-densities from the mean distribution for the whole sky. An extreme case is presented by Hyderabad, $-18°$; other zones, such as Bordeaux, $+15°$, are singularly free from such deviations, and systematic differences must be confined to relatively small areas within the zones.

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[1] Complete references to the data used in the present discussion are given in Table XIII, *Contribution* No. 301.

The reliability and usefulness of the magnitudes is obviously greatest for those cases in which the residuals are small; but, even where there is a marked progression in the residuals, the mean magnitude is still a useful result, in spite of the fact that the uncertainty attached to the brightness of individual stars is correspondingly increased. Moreover, the systematic uncertainty may be less than would be inferred from the run in the residuals. It is assumed that within any zone a given scale-reading corresponds always to the same magnitude; but there are many departures from this ideal state of affairs. Differences in plates, development, and atmospheric conditions; seasonal fluctuations and subjective errors of measurement—all enter as disturbing factors, some of them accidentally, others systematically. Results from individual plates may be seriously

TABLE II

SUPPLEMENTARY VALUES OF LOG N_m

m	Zone	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
9.59....	+31°	0.62	0.55	0.44	0.34	0.28	0.25	0.21	0.18	0.15	0.15
10.72....	+31	1.12	1.04	0.92	0.81	0.73	0.69	0.67	0.64	0.60	0.58
11.89....	+31	1.62	1.54	1.41	1.29	1.18	1.12	1.08	1.06	1.04	1.01
12.89....	+31	1.97	1.90	1.77	1.64	1.55	1.50	1.47	1.45	1.40	1.38
13.48....	+31	2.22	2.14	2.00	1.86	1.76	1.68	1.66	1.63	1.60	1.58
9.76....	+30	0.66	0.61	0.50	0.41	0.35	0.31	0.28	0.27	0.25	0.25
10.85....	+30	1.16	1.11	1.02	0.92	0.83	0.76	0.70	0.64	0.60	0.58
12.09....	+30	1.69	1.64	1.53	1.40	1.28	1.20	1.14	1.12	1.07	1.05
12.92....	+30	1.98	1.93	1.83	1.71	1.60	1.52	1.46	1.41	1.37	1.35
13.70....	+30	2.37	2.28	2.14	1.98	1.86	1.77	1.70	1.65	1.61	1.59
9.36....	+29	0.48	0.44	0.36	0.28	0.23	0.15	0.12	0.09	0.06	0.04
10.28....	+29	0.86	0.81	0.74	0.66	0.61	0.54	0.50	0.46	0.43	0.42
11.50....	+29	1.39	1.32	1.23	1.15	1.09	1.04	0.99	0.92	0.88	0.85
12.52....	+29	1.79	1.72	1.62	1.53	1.44	1.38	1.33	1.30	1.28	1.27
13.55....	+29	2.27	2.20	2.04	1.90	1.80	1.73	1.67	1.63	1.58	1.57
9.20....	+27	0.50	0.42	0.31	0.19	0.09	0.05	0.03	0.01	0.00	9.98
10.12....	+27	0.84	0.79	0.70	0.58	0.48	0.42	0.39	0.38	0.39	0.39
11.35....	+27	1.36	1.28	1.17	1.06	0.97	0.94	0.90	0.89	0.86	0.84
12.25....	+27	1.75	1.67	1.56	1.44	1.33	1.25	1.20	1.19	1.17	1.16
13.28....	+27	2.17	2.10	1.98	1.84	1.69	1.59	1.55	1.53	1.51	1.50
9.31....	+26	0.57	0.48	0.35	0.24	0.16	0.08	0.05	0.03	0.03	0.03
10.33....	+26	0.99	0.92	0.81	0.66	0.54	0.48	0.46	0.45	0.46	0.46
11.58....	+26	1.51	1.43	1.30	1.15	1.02	0.98	0.97	0.95	0.94	0.93
12.54....	+26	1.90	1.83	1.67	1.52	1.39	1.32	1.31	1.30	1.27	1.27
13.48....	+26	2.24	2.19	2.08	1.92	1.76	1.68	1.64	1.57	1.55	1.54
9.58....	+25	0.56	0.52	0.44	0.35	0.27	0.24	0.22	0.20	0.18	0.16
10.63....	+25	1.06	0.99	0.87	0.76	0.67	0.64	0.63	0.62	0.60	0.58
11.90....	+25	1.58	1.53	1.44	1.34	1.20	1.12	1.08	1.05	1.03	1.00
12.73....	+25	1.97	1.91	1.80	1.65	1.49	1.39	1.35	1.33	1.31	1.28
13.53....	+25	2.28	2.22	2.09	1.92	1.77	1.69	1.65	1.61	1.57	1.54
8.97....	−65	0.48	0.40	0.26	0.12	0.00	9.90	9.85	....	....	....
9.47....	−65	0.73	0.64	0.49	0.35	0.20	0.09	0.03	....	....	....
9.90....	−65	0.85	0.81	0.64	0.51	0.40	0.31	0.25	....	....	....
12.29....	−65	1.90	1.79	1.61	1.46	1.35	1.25	1.19	....	....	....

affected; but the formation of means for groups of several plates per hour of right ascension (one hour is the unit interval for grouping the counts) eliminates, or at least minimizes, many of the deviations. Seasonal effects and subjective factors of measurement may remain, however, as persistent systematic disturbances affecting the constancy of the magnitude associated with a given scale-reading; and it is natural to attribute to these sources much of the progression shown by the residuals of Table I.

But it must be noted that at least two other circumstances may contribute to the progression in the residuals: large-scale irregularities in the distribution of the stars and errors in drawing the curves which define log N_m as a function of galactic latitude. The co-ordinates of the centers of the unit areas used for grouping the counts are functions of galactic longitude as well as of latitude. The average effect of galactic concentration has been removed by comparing the observed densities with the mean distribution table; but any systematic deviation in longitude remains in the residuals and may produce an important progressive effect. Further, any tilt of the curve of mean density (as a function of latitude) from its true position operates in the same way. Neither of these, however, affects the adopted relation between scale-reading and magnitude except as it appears in the mean magnitude for the whole zone, where both disturbances are at least partially compensated.

In certain cases the determination of the curve of mean density against latitude presented exceptional difficulty.[1] Thus in the Oxford zones, $+25°$ to $+31°$, the interval 3^h to 6^h of right ascension includes the extensive obscured area in Taurus;[2] the observed densities in this region for each magnitude of every zone are abnormally low, and the systematic effect can be traced through the Paris zones, $+23°$ and $+22°$, down into those of Bordeaux, $+17°$ to $+14°$. Again, the Algiers and San Fernando zones, $-1°$ to $-6°$, show approximately constant densities between 12^h and 18^h of right ascension, although the range in galactic latitude is 50° or more. The

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[1] For an illustration of typical curves, see Fig. 1, *Contribution* No. 135, *Astrophysical Journal*, **46**, 117, 1917. The curve for the Algiers zone and several others used for *Contribution* No. 135 were redrawn in deriving the mean distribution table in *Contribution* No. 301.

[2] Dyson and Melotte, *Monthly Notices*, **80**, 3, 1919.

contrast with the other quadrants of right ascension, which extend over similar intervals in latitude, is striking, and there seems little doubt that the abnormal distribution here is also real. As far as possible, regions of known obscuration were ignored in drawing the mean curves, on the assumption that the removal of the obscuring clouds would reveal a normal distribution of stars. Several instances of this kind are mentioned in the notes following Table XIII of *Contribution* No. 301. It will be the purpose of a later contribution to attempt a separation of these and other real deviations from systematic irregularities which are observational in origin.

The results in Table I include only part of the scale-readings for which counts are available. The calibration could have been completed by the method already used; but a shorter way, which has also the advantage of providing a means of reducing the accidental errors affecting the values already found, is to compare mean densities for entire zones to successive limits of scale-reading with the fifth column of Table XVIII in *Contribution* No. 301, which gives the adopted mean distribution for all latitudes together. Magnitudes found in this way require, however, a small correction because, to a given limit of brightness, the mean density of the stars within a narrow zone in declination is not the same as the mean for the whole sky. The correction, which varies with the declination of the zone, is easily calculated by deriving magnitudes as just suggested for the scale-readings already used and comparing the results with the revised values given in Table I. The quantities $m-m'$ in the last line of this table are the differences in question for these scale-readings.

The procedure is illustrated by the details for the Vatican zones shown in Table III. The total number of stars in the zone to each limiting value of the scale-reading, given in the line opposite N, is taken from the bottom of Table I, *Monthly Notices*, **75**, 602. The number of plates is ten per hour,[1] each having a field of $4\times169/144$ square degrees. To reduce the totals to stars per square degree, we have, therefore, the relation.

$$\log N_m=\log N-3.0518.$$

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[1] *Loc. cit.*, p. 603; or, more conveniently, see Table XIII, *Contribution* No. 301.

The values of the density thus found were used to interpolate the approximate magnitudes m' from the fifth column of Table XVIII, *Contribution* No. 301. These differ systematically from the values of m given in Table I by the quantities $m-m'$, which are the basis for the correction of m'.

The mean values of $m-m'$ vary with the declination and with other circumstances peculiar to the individual zones, such, for example, as the fact that, although regions of known obscuration were ignored in drawing the density-latitude curves used in deriving the values of m, the deficiency of stars in these regions, by affecting the totals N, enters directly into m'. Consequently, the corrections to m' for any zone must be based primarily on the mean $m-m'$ for that zone.

TABLE III

FINAL REDUCTION FOR VATICAN ZONES

Sc.R.	50	40	30	20	10	0
N	887	2201	6139	16750	50283	88782
log N_m	9.896	0.291	0.736	1.172	1.650	1.896
m'	8.35	9.26	10.31	11.37	12.57	13.20
m	....	8.87	10.08	11.15	12.35	12.98
$m-m'$	....	−0.39	−0.23	−0.22	−0.22	−0.22
Corrections	−0.33	−0.31	−0.28	−0.25	−0.24	−0.24
Adopted m	8.02	8.91	10.06	11.14	12.34	12.97

Further, some variation in $m-m'$ with brightness is also to be expected. This was investigated by forming the deviations of the values of $m-m'$ given in Table I from the means for the separate zones and arranging the results according to brightness for groups of zones covering a moderate range in declination. Within the precision of the data, the variation in $m-m'$ thus found is independent of declination, and is represented by the following mean values:

m'	8	9	10	11	12	13
Var. in $m-m'$	−0.08	−0.05	-0.02^5	0.00	+0.02	+0.02

The adopted correction to any m' has therefore the form

$$\text{Mean } m-m' + \text{Variation in } m-m' .$$

Thus for the Vatican zones, the mean $m-m'$ is −0.26. For scale-reading 50, $m'=8.35$, and from the foregoing tabulation the varia-

TABLE IV

INTERNATIONAL PHOTOGRAPHIC MAGNITUDES FOR ASTROGRAPHIC ZONES

VATICAN

Sc.R.	50	40	30	20	10	0
+62°	8.02	8.91	10.06	11.14	12.34	12.97

OXFORD

Sc.R.	45	35	26	18	12	All
+31°	8.43	9.60	10.70	11.90	12.89	13.48
+30	8.66	9.79	10.86	12.06	12.92	13.69
+29	8.30	9.39	10.32	11.52	12.48	13.51
+27	8.24	9.20	10.13	11.35	12.24	13.28
+26	8.25	9.32	10.34	11.56	12.52	13.48
+25	8.49	9.56	10.63	11.89	12.77	13.52

Sc.R.	50	40	30	18	12	9	7	5	3	All
+28°	7.95	8.99	10.05	11.57	12.43	13.08	13.31	13.49	13.55	13.62

PARIS

Sc.R.	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	All
+23°	9.14	9.72	10.39	11.05	11.72	12.30	12.80	13.14	13.34
+22	9.20	9.72	10.35	10.97	11.70	12.27	12.79	13.17	13.42

BORDEAUX

Sc.R.	6.5	7.0	7.5	8.0	8.5	9.0
+17°	8.05	8.73	9.35	10.07	10.72	11.41
+16	7.18	....	8.60	....	10.06	....
+15	6.43	....	7.78	....	9.66	....
+14	6.89	....	8.13	....	9.96	....

TABLE IV, BORDEAUX—*Continued*

Sc.R.	9.5	10.0	10.5	11.0	11.5	12.5
+17°	11.91	12.35	12.65	12.93	13.13	13.17*
+16	11.49	....	12.28	....	12.70	12.77
+15	11.26	....	12.18	....	12.61	12.65
+14	11.52	....	12.50	....	12.99	13.00

* This value corresponds to Sc.R. 12.0.

TOULOUSE

Sc.R.	8.0	8.5	9.0	9.5	10.0	10.5
+9°	8.63	9.06	9.71	10.34	10.69	11.05

Sc.R.	11.0	11.5	12.0	12.3	....	....
+9°	11.44	11.81	12.19	12.55	....	....

ALGIERS

Sc.R.	6.9	7.9	8.9	9.9	10.9	11.9
−1°	8.12	9.20	10.92	11.47	12.37	12.96

SAN FERNANDO

Sc.R.	8.0	8.5	9.0	9.5	10.0	10.5
−3°	9.43	10.16	10.91	11.61	12.22	12.73
−4	9.14	9.98	10.76	11.48	12.16	12.60
−5	9.19	9.99	10.73	11.42	12.03	12.50
−6	9.30	10.04	10.70	11.34	11.87	12.30

Sc.R.	11.0	11.5	All	....	....	....
−3°	13.04	13.21	13.25	....	....	....
−4	12.84	12.96	13.00	....	....	....
−5	12.77	12.99	13.06	....	....	....
−6	12.60	12.83	12.90	....	....	....

TACUBAYA

Sc.R.	8.0	8.5	9.0	9.5	10.0	10.5
−15°	9.28	10.00	10.66	11.28	11.94	12.50
−16	9.11	9.86	10.51	11.26	11.88	12.50

TABLE IV, TACUBAYA—*Continued*

Sc.R.	11.0	11.5	....	....	....	....
−15°........	12.97	13.28	....	....	....	....
−16........	13.06	13.30	....	....	....	....

HYDERABAD

Sc.R.	50	40	30	20	12	8
−17°........	9.54	....	11.31	12.13	12.75	13.36
−18........	9.60	....	11.43	12.16	12.79	13.34
−19........	9.32	10.18	11.36	12.18	12.90	13.28

CORDOBA

Sc.R.	51	41	31	21	11	1
−25°........	7.36	8.68	9.99	11.41	12.89	13.30
−27........	7.43	8.61	10.08	11.44	12.82	13.04
−29........	6.73	7.83	9.27	10.76	12.48	12.98
−31........	6.53	7.58	9.14	10.65	12.59	13.20

PERTH

Sc.R.	A	B	C	D	E	F
−32°........	8.63	9.20	9.83	10.33	10.89	11.46
−34........	8.49	8.92	9.50	10.15	10.89	11.45
−36........	8.92	9.40	10.03	10.64	11.31	11.80

Sc.R.	G	H	J	K	L	M
−32°........	11.98	12.45	12.81	13.05	13.16	13.16
−34........	12.06	12.54	12.87	....	....	13.22
−36........	12.36	12.76	13.08	....	....	13.51

PERTH-EDINBURGH

Sc.R.	50	40	30	20	10	All
−38°........	8.30	9.33	10.08	11.34	12.89	13.52

CAPE

Sc.R.	300	200	170	150	130	110
−41°........	....	9.60	9.94	10.22	10.71	11.33
−42........	7.88	9.46	....	....	....	....
−43........	7.98	9.58	....	....	....	....

TABLE IV, CAPE—*Continued*

Sc.R.	100	80	60	−1	−2	−5
−41°........	11.76	12.14	12.38	12.52	12.69	13.46*
−42........	11.84	....	12.50	....	....	13.58
−43........	11.82	....	12.48	....	....	13.52

* Additional values for −41°: −3, 12.90; −4, 13.16.

MELBOURNE

Sc.R.	41	36	31	26	21	16	11	All
−65°........	7.90	8.50	8.96	9.46	9.92	11.01	12.28	13.09

NOTES TO TABLE IV

The magnitudes listed in Table IV refer to the faintest stars to which the respective scale-readings have been assigned. The average magnitude corresponding to any scale-reading is brighter than the tabular value by approximately one-half the magnitude interval covered by the step in scale-reading.

Vatican: Results are mean values for zones +64°, +62°, and +60°.

Bordeaux: Difference in scales especially noticeable for +17°. See *Monthly Notices*, **79,** 140.

Toulouse: See note to Table I.

Algiers: The large irregularity in the scale has been discussed by Turner, *ibid.*, **72,** 701.

Melbourne: The images were measured on three different machines, for one of which there is an important systematic difference. See *ibid.*, **77,** 36.

tion in $m-m'$ is −0.07, which gives a total correction of −0.33 and an adopted limiting magnitude of 8.02. For those cases in which a value of m is available from Table I, the adopted magnitude is the mean of m and the corrected m'. The agreement in the pairs of values thus found is excellent, the mean difference being ±0.04 mag. The use of means tends to smooth out accidental errors in m arising from uncertainty in drawing the density-latitude curves, which may be systematically too high or too low. The final results in the last lines of Table III appear in Table IV along with those for the other zones, which were all treated by the method outlined.

In using Table IV it is important to bear in mind a point already mentioned, namely, that the magnitudes refer to the faintest stars included among those to which the corresponding scale-reading has been assigned. A more useful tabulation of results would have been one giving average values of the magnitude corresponding to the respective scale-readings. These differ from the values appearing in Table IV by approximately one-half the magnitude interval corresponding to the smallest interval of scale-reading used to express the brightness of the stars. The step in scale-reading differs from zone to zone, and since the actual values were not always available, the results are necessarily presented as in Table IV.

It is also to be noted that Table IV pretends to be nothing more than an average calibration of the respective scales. Nevertheless, the residuals in Table I show that in many instances this calibration is directly applicable to small parts of a zone. Further, it should be recalled that, even when the residuals of Table I are systematic, the average calibration may be better than the residuals indicate, for large-scale irregularities in stellar distribution and certain errors involved in the method of reduction contribute to the progressive character of the residuals. Magnitudes for individual stars derived with the aid of Table IV, for obvious reasons, will be subject to a relatively large uncertainty.

MOUNT WILSON OBSERVATORY
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PLANETARY TEMPERATURES DERIVED FROM WATER-CELL TRANSMISSIONS

By D. H. MENZEL, W. W. COBLENTZ, and C. O. LAMPLAND

ABSTRACT

In this paper the measurements of the planetary radiation transmitted through a water cell as observed by Coblentz and Lampland at the Lowell Observatory during the summer of 1924 are reduced by Menzel by the method published by him in this *Journal* in 1923.

The *results* obtained seem to prove quite conclusively that the *bright areas are at a lower temperature than the dark areas*, and that the *equatorial (black-body) surface temperature of Mars at perihelion rises above 0° C.* The true temperature, corrected for emissivity, would be about *10°* higher. The temperature of the *south polar cap was −100° C.* on August 14, gradually *increasing to about −15° C.* on October 22, indicating that the cap is probably composed of ice and snow. The low temperature of the east limb, which was down to *−85° C.*, is definite proof of an *enormous diurnal fluctuation.* Various methods of combining the observations give concordant results.

The temperature of the *moon reached 120° C.* under perpendicular insolation. The distribution of energy in its heat spectrum is not consistent with a radiating surface of quartz.

The temperatures of *Jupiter, Saturn, and Uranus* are *low*, the values calculated from the water-cell transmissions being *−130° C.*, *−150° C.*, and *−170° C.*, respectively. There is little evidence of internal heat.

I. THEORY

During the summer and fall of 1924 an extensive series of radiometric measurements was made on the planets, especially Mars, by Coblentz and Lampland at the Lowell Observatory, Flagstaff, Arizona.[1] By means of suitable screens of water, quartz, glass, and fluorite the radiation emanating from the planets was separated into spectral components and thereby an estimate of planetary temperatures was obtained. At the conclusion of these measurements it seemed fitting to have Menzel participate by calculating the planetary temperatures from the observed water-cell transmissions employing the method used by him[2] on similar data obtained by these same observers in 1922. The present paper contains a discussion of the planetary temperatures as deduced by Menzel from the water-cell transmissions.

A water cell 1 cm in thickness transmits radiation which lies between 0.3 and 1.4 μ, while the screens of quartz, glass, and fluorite

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[1] *Journal of the Franklin Institute*, **199**, 785; **200**, 103, 1925.

[2] *Astrophysical Journal*, **58**, 65, 1923.

are transparent up to 4 μ, 8 μ, and 12.5 μ, respectively. For further details regarding the method, etc., see previous publications.[1]

The radiation which falls upon the thermocouple is made up of two parts: reflected solar energy of short wave-length and radiated planetary energy of long wave-length. Certain fractions of each are absorbed in passing through the earth's atmosphere. The derivation of the transmission coefficients has been fully discussed in the earlier paper by Menzel[2] and need not be repeated here. New values were calculated for the long-wave transmissions, since the earlier measures were made with a thermocouple having a fluorite window. As a rock-salt window was employed in the present observations, it was necessary to consider the additional energy lying between 12.5 μ and 15 μ, the latter being the limit of transparency of the earth's atmosphere. The values of the atmospheric transmission for this long-wave radiation, computed from two sources,[3] gave almost exact agreement, suggesting that little error is introduced here. The final data are contained in Table I.

TABLE I

TRANSMISSION OF BLACK-BODY RADIATION THROUGH ATMOSPHERE

Temperature	100	150	200	250	300	350	400	500	600
Percentage	0.5	5.7	14.6	22.4	27.4	29.7	30.5	30.4	30.1

The connection between the water-cell transmissions and planetary temperatures[4] is as follows:

$$\frac{t}{t'}\,\frac{q}{\phi A}\,\frac{e}{x}\,\frac{T^4}{T_0^4}=\frac{0.755}{W}-1\,. \tag{1}$$

In this equation t and t' are the atmospheric transmissions for long-wave and short-wave radiation, respectively. The former is also multiplied by 1.1 because the infra-red is more completely reflected

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[1] Coblentz, *Scientific Papers of the Bureau of Standards*, Nos. 438 and 460, 1922.

[2] *Loc. cit.*

[3] *Smithsonian Physical Tables* (7th ed.), p. 308, and Edison Pettit and Seth B. Nicholson, *Publications of the Astronomical Society of the Pacific*, **35**, 195, 1923.

[4] Menzel, *op. cit.*, p. 67.

than the visual at the mirror of the telescope. A is the planet's albedo, q is a factor which takes account of the variation of the light with phase. The factor x allows for any spottedness or inequalities of illumination of the planet and may be defined as the ratio of the brightness of the region under investigation to the average brightness of the entire surface. The factor e is the emissivity; for a perfect radiator, $e=1$. T_0 is defined by the following equation,

$$T_0=392^\circ\cdot R^{-\frac{1}{2}},$$

where R is the planet's distance expressed in astronomical units. The logic of equation (1) may be summed up as follows. T_0^4 is proportional to the intensity of incident solar radiation; combined, as above, with t, q, ϕ, A, and x, it represents the quantity of reflected energy which reaches the thermocouple. As the values of all these factors are known, the amount of this energy can be computed with considerable accuracy. The long-wave planetary radiation is proportional to T^4, T being the surface temperature.

Since the water-cell transmission, W, is an indirect measure of the ratio of solar to the total energy, the value of T, the only unknown, may be derived. The planet's albedo for the total incident sunlight is assumed to be equal to the visual albedo. For Mars this is probably a good approximation; the albedo for the blue being less, and for the red, greater. When only a portion of the illuminated disk was on the thermocouple, x was taken equal to the ratio of the illuminated portion of the apparent disk to the area of the entire disk regarded as circular, this quantity being tabulated in the *American Ephemeris and Nautical Almanac*. When the thermocouple covers the whole planet, x is unity.

The two factors, W and x, though somewhat uncertain, enter into the equations only as the fourth root; a condition which is fortunate, considerably reducing the errors in the computed temperature. The numerical value of $W=0.695$ in the original equation has been divided by 0.92, to correct for reflection. Since the observed water-cell transmissions are treated in the same manner, the factor cancels and the equation has the same meaning as in the earlier paper.

2. TEMPERATURE OF MARS FROM WATER-CELL TRANSMISSIONS

Table II contains the temperatures of Mars expressed on the absolute scale and the observed water-cell transmissions (*W*) from which they are computed. Since *e* was here assumed equal to unity, the true surface temperatures will be higher. For the range considered, *t* varies approximately as T^2, and the observed black-body temperatures must therefore be multiplied by $e^{-1/6}$. Assuming $e=0.8$, a reasonable estimate, then all the temperatures are to be multiplied by 1.03, amounting to an increase of approximately 10° in each case.

TABLE II

TEMPERATURES OF MARS COMPUTED FROM WATER-CELL TRANSMISSIONS

DATE	EAST		WEST		NORTH		SOUTH		CENTER		REMARKS
	W	*T*°	*W*	*T*°	*W*	*T*°	*W*	*T*°	*W*	*T*°	
June 24	......	......	......	......	......	......	......	......	0.418	237	
June 25	......	......	......	......	......	......	......	......	.511	250	Fluorite windows
June 25	......	......	......	......	......	......	......	......	.388	242	
July 22	......	......	......	......	......	......	......	......	.374	254	
Aug. 1	0.423	243	0.370	256	......	......	......	......	.370	256	Short focus
Aug. 14	.520	227	.354	268	0.741	150	0.720	165	.308	282	
Aug. 15	.542	222	.364	266	......	......	......	......	.324	278	
Aug. 18	......	......	......	......	......	......	......	......	.311	277	
Aug. 21	......	......	......	......	.790	?	.716	165	.325	276	
Aug. 21	......	......	......	......	......	......	......	......	.349	268	
Aug. 23	.558	218	.356	266	.734	155	.695	180	.328	275	
Aug. 25	......	......	......	......	......	......	......	......	.337	266	
Aug. 28	......	......	......	......	......	......	......	......	.312	277	
Sept. 11	.663	187	.364	260	.725	160	.625	200	.308	274	
Sept. 12	.661	187	.336	266	.693	180	.605	205	.324	270	South cap
Sept. 12	......	......	......	......	......	......	.545	220	......	......	Meridian
Sept. 13	0.382	255	0.253	295	.336	266	.264	292	.251	295	Short focus
Sept. 13	......	......	......	......	......	......	......	......	.271	287	Short focus
Sept. 13	......	......	......	......	......	......	......	......	.296	275	
Sept. 14	......	......	......	......	......	......	.292	279	.293	279	Short focus
Oct. 15	......	......	......	......	......	......	......	......	.332	273	
Oct. 22	......	......	......	......	0.795	?	0.329	260	0.295	268	

Unless a note is affixed to the contrary, the observations were all made at the long focus (53.3 ft.) of the 40-inch reflector, the diameter of the receiver being only 0.11 that of the planet's disk during August and September and 0.2 during October. In the observations at the short focus (18.4 ft.), the relative diameters were 0.35 on August 1 and 0.5 for the remaining dates. In the first four measures (June and July) the receiver covered the entire disk of the planet. The temperatures at the two foci are only to be compared judiciously; note the observations of September 13. Obviously, when observing at the shorter focus, the higher temperatures of the poles and limbs are owing to the greater and warmer area near the equator falling on the receiver. For similar reasons, the lower temperatures on the equator are owing to the colder areas of the temperate zone intercepted by the receiver.

The observed decrease in the temperature of the east limb, while the west, north, and center remain approximately constant, is striking, and is quite in accord with what might be expected.[1] Figure 1 shows the relative positions of the earth and Mars on the various dates. When, on August 1, the thermocouple was set upon the east limb, it covered an area at a considerable distance from the limb, while on September 13 the limb itself was observable. The observations, therefore, record the rise in temperature as the surface is warmed by the morning sun. The lowest temperature recorded for the east limb is 187° Abs., which is probably near to or somewhat greater than the night temperature of the planet, agreeing well with the previous estimate.[2] The measures show that the Martian afternoon is considerably warmer than the morning.

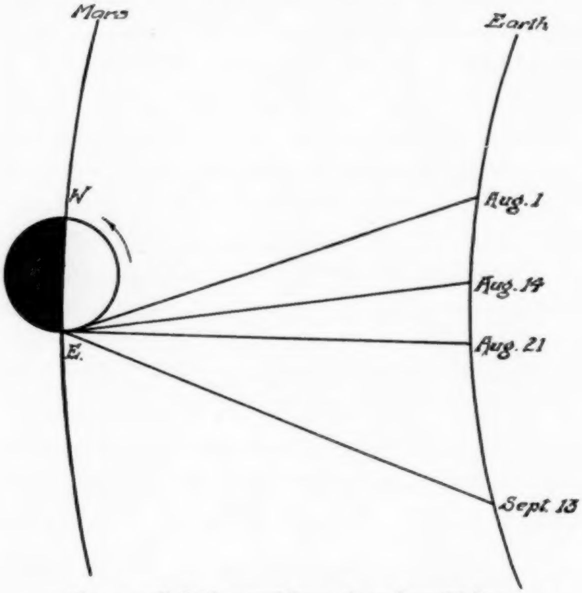

FIG. 1.—Relative positions of earth and Mars

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[1] Coblentz and Lampland, *Journal of the Franklin Institute*, **199**, 1925.

[2] Menzel, *loc. cit.*, p. 72.

The rise of the south polar temperature as the season advances also might have been predicted. The temperatures given in Table II were computed, using $x=1$. Since the polar cap is considerably brighter than the rest of the planet the foregoing values must be considered as a minimum. For $x=3$, which is not unreasonable, the temperatures for the first six observations become 195°, 195°, 210°, 236°, 245°, and 264°, respectively, allowing the possibility that, at the edge of the cap, the temperature may read 0° C., the necessary condition that the phenomenon of disappearance be ascribed to melting snow and ice.

The high temperature of the south polar region is no doubt owing to the fact that this portion of the planet is turned toward the sun and does not have to undergo the extreme diurnal fluctuations of the lower latitutes. The order of magnitude of the temperature is confirmed by the well-known argument concerning the relative behavior of the southern and northern caps. The former is often seen entirely to disappear while the latter never quite vanishes. This is explained by the great eccentricity of the planet's orbit—the south pole being turned toward the sun at perihelion and away at aphelion.

The equatorial midday temperatures are approximately constant and above 0° C., being somewhat lower for the bright than for the adjacent dark areas.

3. THE SPECTRAL DISTRIBUTION OF PLANETARY RADIATION

If a planet were a perfect radiator, its temperature could be derived from the spectral distribution of the energy in its heat spectrum. The fluorite and glass screens are transparent as far as 12.5 μ and 8 μ, respectively. From their values the observed ratio of the energy in the region 8 μ–12.5 μ to that in 12.5 μ–15 μ may be obtained.[1] The observed distribution, when compared with the theoretical, calculated from Planck's formula taking into account the absorption by the atmosphere and various screens, gives values of the Martian temperature in good agreement with the temperatures derived from the water-cell transmissions.

Various factors, such as atmospheric absorption, emissivity, and

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[1] Coblentz and Lampland, *Journal of the Franklin Institute*, **199**, June-July, 1925.

deviation from black-body law, affect the temperatures calculated by this method much more than those computed by the formula of section 1, since the latter depends on the quantity of radiated energy which is not as sensitive to these factors as is the spectral distribution. Therefore, even if the ratio method fails, the method of water-cell transmission will still give at least the order of magnitude of the temperature. The observed spectral components for the moon show that there is more energy in the region 8 μ–12.5 μ in proportion to the amount in 12.5 μ–15 μ than a black-body of similar temperature would radiate. In passing, it may be pointed out that this behavior indicates that the lunar surface is evidently not composed of quartz, which has a reflection maximum at 9 μ and should, therefore, exhibit a smaller instead of a greater relative emissivity in this region.

The planets with heavy atmospheres—Venus, Jupiter, and Saturn—show a marked selectivity, the observed ratios being much greater than black-body conditions would allow.

4. WATER-CELL TRANSMISSION TEMPERATURES OF OTHER OBJECTS

Venus, Jupiter, Saturn, and Uranus were also observed. The resulting temperatures are given in Table III. The value for Venus is somewhat in doubt, owing to the uncertainty in x. The temperatures calculated from the recent measurements by Coblentz and Lampland on the giant planets confirm the preliminary investigation by Menzel. The lower values are a confirmation of the work of

TABLE III

WATER-CELL TRANSMISSIONS AND CALCULATED PLANETARY TEMPERATURES

	Date, 1924	W	T°
Venus	Aug. 25	0.634	330
Jupiter	June 20	.728	140
	Aug. 16	.746	120
Saturn	June 20	.669	130
	June 21	.682	125
Uranus	....	0.755	100*

* Upper limit.

Jeffreys,[1] who, independently and on theoretical grounds, suggested that the temperatures of these planets are low and maintained by solar radiation alone, internal heat contributing little or nothing. There is, therefore, no necessity for assuming the large quantities of radioactive material necessary to explain the higher provisional temperatures, as Jeffreys does in a more recent article.[2]

The temperature assigned to Uranus is a maximum. Any body with a temperature less than 100° Abs. will radiate practically all of its energy in wave-lengths longer than 15 μ, which are not transmitted through the atmosphere.

Table IV sets forth the results of the observations on the moon. W is the water-cell transmission, i the altitude of sun above the lunar horizon (greater than 90° for the afternoon), and T_w the observed temperatures. In the last column, for the sake of comparison, are given the temperatures, T_d, computed by Dietzius[3] for corresponding insolation. They were derived by an application of the well-known heat theorems and the Fourier series for its conduction.

TABLE IV

LUNAR TEMPERATURES

Date	W	i	T_w	T_d
June 24	0.126	105°	390°	382°
Aug. 6*	.101†	65	395†	365
Aug. 15	.241	16	320	236
Aug. 18	.171	55	360	352
Aug. 20	.155	78	370	377
Aug. 25*	.158	140	365	354
Sept. 12	.174	138	350	356
Oct. 5	0.132	80	380	379

* Poor series.

† Observation and therefore T_w, uncertain.

In general, a very good agreement is indicated for T_w and T_d, except on August 15, when a temperature some 80° higher was observed.

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[1] *Monthly Notices of the Royal Astronomical Society*, **83**, 350, 1923.

[2] *Ibid.*, **84**, 537, 1924.

[3] *Sitzungsberichte der Akademie der Wissenschaften*, **132**, 194, 1924.

5. FURTHER NOTES REGARDING PLANETARY TEMPERATURES

If the observations could be made outside the atmosphere, a given planet would have the same water-cell transmission no matter what its distance from the sun—and this would be independent of its surface temperature, provided that the planet has no internal heat. This may be proved as follows:

Let A be the planet's albedo and E the amount of energy it receives at any given distance. The quantity reflected will be AE; that absorbed will be $(1-A)E$; and that re-radiated in the direction of the earth will be $K(1-A)E$, K being a constant less than unity, taking care of the possibility of some of the heat being carried by rotation to the far side of the planet. For a non-rotating body $K=1$.

The transmission, then, is proportional to

$$\frac{AE}{AE+K(1-A)E}=\frac{A}{K+(1-K)A}\,.$$

Since the energy cancels out, the transmission is mainly a function of albedo and not of position.

The presence of the earth's atmosphere alters the case. Since it transmits practically only the energy which lies between 8 μ and 15 μ, the amount of planetary energy which gets through depends upon its spectral distribution and therefore upon the temperature. While the ratio of solar to planetary energy is constant outside the atmosphere, a greater amount of the latter will be absorbed the lower the temperature of the radiating surface. The observed water-cell transmissions of the same object should increase with distance from the sun.

The fact that Mars and the moon are somewhat similar explains the relation exhibited by curve A (Fig. 2). The higher albedo and lower temperature cause the water-cell transmissions of Mars to lie on the same straight line as those of the moon. Table V, column 5, gives the Martian temperatures read off from the curve.

Curve B (fig. 2) also shows that the ratio of the spectral components (see sec. 3) for Mars and the moon are connected by an approximate linear relation. A few lunar observations (which are known to be defective) are so discordant that it is practically impossible to judge the position of the line from these measures alone. Taken with the water-cell transmission temperatures, however, they serve to define the end-points and general slope. The ratios of the observed Martian components and their corresponding temperatures are given in column 6 of Table V. The true tempera-

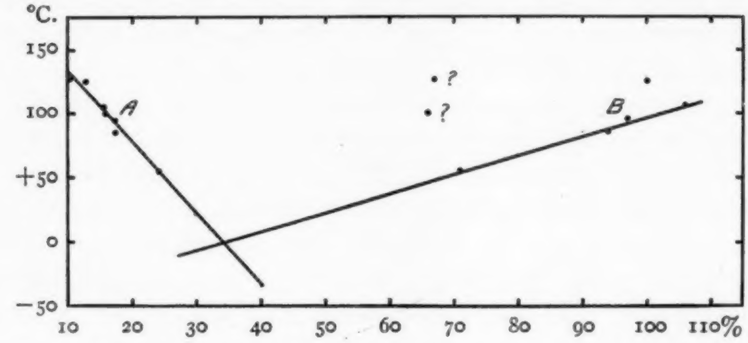


FIG. 2.—Lunar temperatures calculated from the observed water-cell transmissions (curve *A*) in percentage. In curve *B* the temperatures calculated from the water-cell transmissions are plotted against the observed ratios *A : B* of the spectral components of planetary radiation.

TABLE V

TEMPERATURE OF MARS

DATE, 1924	*W* PERCENTAGE	RATIOS *A*:*B*	TEMPERATURES, °C.				REMARKS
			1	2	3	Mean	
Aug. 14....	30.5	41.3	9	16	10	12	Aug. 1–Sept. 13, 53-ft. focal length
Aug. 15 ...	32.4	43.1	5	9	13	9	Mare Sirenum, dark
Aug. 18....	31.1	38.6	4	15	6	8	Mare Sirenum, dark
Aug. 21....	32.5	40.7	3	8	9	7	Mare Sirenum dark
Aug. 21....	34.9	39.1	−5	−4	7	−1	Bright area north of Mare Sirenum
Aug. 23....	32.8	36.6	2	6	3	4	Bright area north of Mare Sirenum
Aug. 25....	33.7	38.3	−7	2	5	0	Bright area north of Beak of Sirens
Aug. 28....	31.2	50	4	15	24	14	Solis Lacus, dark
Sept. 11....	30.8	47.8	1	16	20	12	Syrtis Major, dark
Sept. 13....	29.6	39.3	5	23	7	12	Syrtis Major, dark
Sept. 13....	25.1	55.8	22	50	32	34	18.4-ft. focal length; Syrtis Major
Sept. 14....	29.2	46.4	6	24	18	15	South Pole, 18-ft. focal length
Sept. 14....	29.3		6	24		16	Mare Cimmerium, dark
Oct. 15....	28.0		0	33		16	....

Col. 1 is calculated from the observed water cell transmissions (*W*) of the radiation from Mars, using the fourth-power law; col. 2 by extrapolation from the water-cell transmissions and similarly calculated temperatures of the moon; col. 3 by extrapolation from the ratios of the observed spectral components *A* : *B* of the radiation from the moon and the lunar temperatures calculated from the lunar water-cell transmissions, to the observed spectral components, *A* : *B* of Mars.

tures would be 8° to 10° C. higher. The mean values are given in column 7 of the table, but, since the temperature data on Mars given in the last two columns are obtained by a large extrapolation from the temperatures of the moon, more weight should be given to the values in column 4 of Table V, which were computed from the formula in section 1, than to the extrapolated values. However, they are interesting in confirming the direct measurements on Mars which show that the bright areas are cooler than the dark areas.

July 4, 1925

PHOTOGRAPH OF SHADOW BANDS

By A. E. DOUGLASS

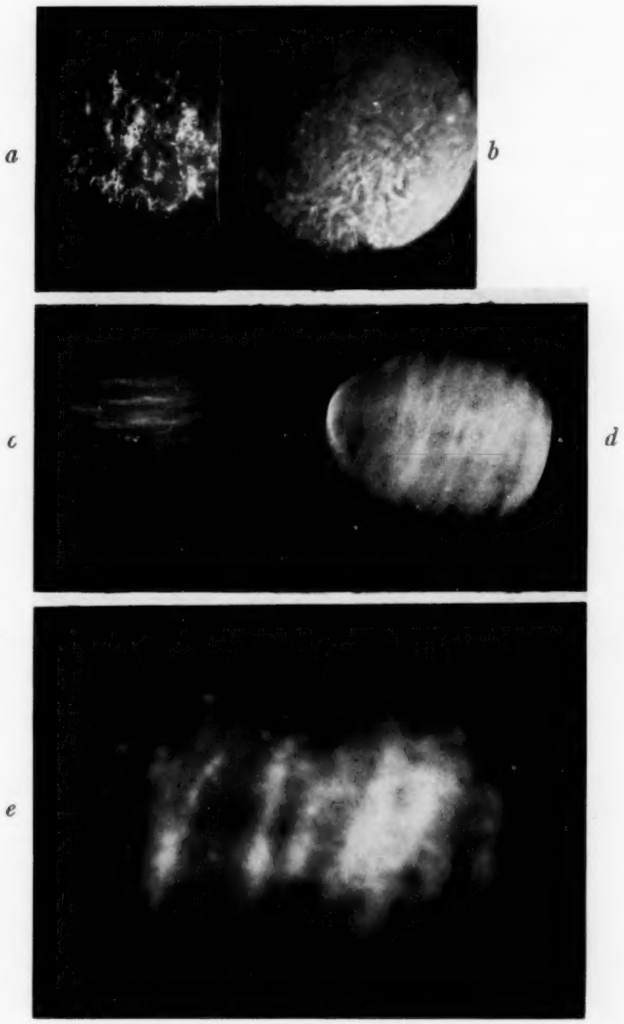
ABSTRACT

The author's earlier experiments in *photographing heat-currents and atmospheric waves* indicated that the apparatus could be used also for photographing the *shadow bands* at a *total solar eclipse.* This was accomplished on *January 24, 1925,* at Middletown, Connecticut, with the author's apparatus, under the auspices of the expedition from the Harvard Astronomical Laboratory.

Some years ago the writer made extended studies of atmospheric currents. As this work progressed, attempts were made to photograph the waves or nodules of varying density in the atmosphere. A very faint impression was obtained by direct exposure of a plate to a distant locomotive headlight, using a crude focal-plane shutter. A device was then arranged for increasing contrasts, and successful photographs were made of heat currents over candle, lamp, etc., and of the atmospheric waves in daytime under full sunlight (Plate XI*a*). This apparatus consisted essentially of a concave silver-on-glass mirror of 12-, and later, one of 13-inch diameter. The beam from an arc light was reflected by the mirror and brought to a focus, and was then allowed to pass some inches beyond to the photographic plate. Close in front of the plate, or at the focus, was placed the shutter. This combination produced an out-of-focus image of the source of light, and in this image the heat currents were reproduced with greatly increased contrasts.

It was recognized at that time that shadow bands could be photographed in this manner. The writer had observed that phenomenon in previous total eclipses, and had noted its relationship to the direction of the solar crescent. Its explanation as an atmospheric phenomenon modified by the shape of the source of light seemed probable. To test this a photograph of artificial shadow bands was made. The solar crescent was represented by a suitable crescent cut in black paper. The diameter of the artificial sun was 1 foot and its distance was 100 feet from the photographic apparatus. The illumination came from a large mirror, behind the crescent, reflecting sunlight. The concave mirror and photographic plate were

PLATE XI



a, Atmospheric currents in full sunlight (1901)
b, Heat waves over a lamp (1901)
c, Artificial shadow-bands (1901)
d, Shadow-bands photographed at Middletown, Connecticut, January 24, 1925
e, Enlargement of *d*, showing about 9 inches of width

placed in a room darkened as much as possible. A lighted lamp was placed under the beam of light. When the source of light was very small, for example, a quarter-inch circle, the heat currents over the lamp appeared just as they had been photographed; but, when the long thin crescent was used, the currents were modified so that they appeared lengthened in a direction parallel to the crescent, and much other detail was lost. Plate XI*b* shows the heat currents over the lamp taken in this way, and *c* shows the result on using the thin crescent. The heat current in the latter contained undoubtedly the very same sort of waves as before.

That experiment years ago fixed the writer's opinion as to the atmospheric origin of the shadow bands, but the actual shadow bands had not been photographed, and after the eclipse of 1923 it was recognized that there was still some doubt of their cause in the minds of some astronomers. Accordingly, in January last, on return from an eastern trip, I prepared an apparatus which used a 13-inch mirror in the manner described above. This mirror, with its mounting, was forwarded to Middletown, Connecticut, to Dr. H. T. Stetson, of the Harvard Astronomical Laboratory. It was placed by him in charge of Mr. David P. Mann, chief mechanician of the Jefferson Physical Laboratory, who was assisted by Mr. Gell. Mrs. Stetson did the counting of time during the eclipse. A dozen exposures were made in the five minutes including the total phase, four of these during totality. The only one showing shadow bands was made immediately before totality, when the diminishing crescent of the sun was approximately 40° long (Plate XI*d* and *e*). Exposures, when the crescent was 70° and 100° long and over, did not show the bands. It is evident that the interval for obtaining good results is short, and one must seize just the right moment while the solar crescent is thin and short. Of course, as the source of light is disappearing, the quantity is decreasing with the greatest rapidity, and at the same moment the definition and contrast of the bands are improving with equal speed. Evidently this method could be nicely adapted to a moving-picture camera in which the speed of very rapid exposures can be fully controlled. A moving-picture of shadow bands would give a very full record of them and supply meteorological data of unusual kind.

Figure 1 shows the apparatus as arranged for photographing shadow bands. The full aperture of the mirror is exposed to the sun, and the film box is in its outside position so that the actual focus comes at the front (right) end of the box. A very crude homemade shutter was used at this point. The film was of the ordinary type for a small camera, and was mounted so as to turn from the outside. A small telescope was fixed to the top of the camera box to serve as finder. A screen was placed near its eye-end so that the sun's image could be watched. As soon as totality began, the aperture of the mirror was reduced to 3 inches by a movable diaphragm, and the film box was moved nearer the mirror so that the film itself was at the focus. In this position a picture of the corona was obtained. When totality was half over, the apparatus was returned to the shadow band arrangement.

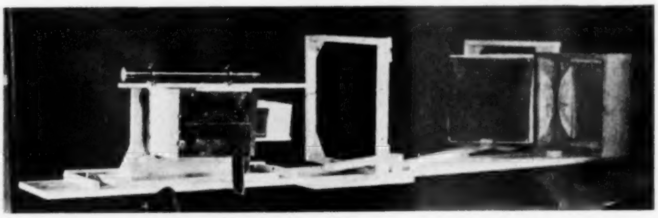


FIG. 1.—Shadow-band camera, 1925. At the right is the 13-inch concave mirror in the box, with movable 3-inch diaphragm near it. At the left, film box with finder attached.

Mr. Mann and his associates had only one day before the eclipse for going over the voluminous directions for setting up and operating this apparatus and for practice with it. It was due entirely to their skill that a picture of these very faint bands was obtained.

UNIVERSITY OF ARIZONA
October 27, 1925

OBSERVATIONS ON THE STARK EFFECT OF SECOND ORDER

By J. STUART FOSTER

ABSTRACT

The observed average second-order Stark effect for six perpendicular components of $H\delta$ in a field of 65 kv/cm is 0.40 A. On the same plate the central perpendicular component of $H\epsilon$ is displaced 0.73 A. The shifts calculated from the Epstein formula are 0.30 and 0.79 A, respectively.

The central perpendicular component of the so-called parhelium group including λ 4009 (comparable in a sense to $H\epsilon$) is displaced toward the red 0.35 A in a field of 60 kv/cm.

No Doppler effect is found for neutral helium lines from a hydrogen-and-helium-gas mixture in a field of 50 kv/cm. As the Balmer lines were not so tested, it is still possible that the characteristic haze which surrounds their Stark components may be due to light from a comparatively small number of atoms which have gained high velocities as positive ions.

According to the present data, the agreement between calculated and observed effects of the second order in hydrogen improves with increasing order.

In 1919 T. Takamine and N. Kokubu[1] reported a shift toward the red of about 1.0 A for the central perpendicular Stark component of $H\gamma$ in the unusually high field of 130 kv/cm. This important fact was clearly shown in a photograph of $H\gamma$ included in the report. It was also observed that the central perpendicular component of $H\epsilon$ was similarly affected by high fields, though the displacement was not measured. Attention was further directed to the helium lines λ 4388 and λ 4026, which showed an analogous effect.

This report was made without knowledge of an earlier paper by P. Epstein[2] in which exactly such an effect in hydrogen was anticipated. Superimposed upon the first-order effect, in which each component $(m_1\, m_2\, m_3 \rightarrow n_1\, n_2\, n_3)$ is displaced in proportion to the field strength, the theory predicts a relatively small effect of the second order consisting of a shift of all components toward the red by an amount depending upon the square of the applied field, and given by

$$\Delta_2\nu=\frac{17}{16}\frac{h^6F^2}{(2\pi)^6e^2E^4m_0^3}\{Z_2(n)-Z_2(m)\}\ ,$$

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[1] *Mem. Coll. Sci., Kyoto*, **3**, 271, 1919.

[2] *Annalen der Physik*, **51**, 168, 1916.

where

$$Z(n)=(n_1+n_2+n_3)^6\left\{1-\frac{3}{17}\left(\frac{n_2-n_1}{n_1+n_2+n_3}\right)^2-\frac{9}{17}\left(\frac{n_3}{n_1+n_2+n_3}\right)^2\right\}$$

and F is the applied electric field. For the first four members of the Balmer series Epstein has thus calculated second-order shifts amounting to 0.03, 0.09, 0.27, and 0.73 A, respectively, in a field of 104 kv/cm.

These important theoretical connections were pointed out by A. Sommerfeld,[1] who verified the calculations. Thereupon Takamine made a careful re-examination of $H\gamma$ on his original plate, and found a corrected shift of 0.75 A in a field of 147 kv/cm. In addition, he observed that the perpendicular components adjacent to the central one were displaced toward the red by the same amount. The theoretical shift at 147 kv/cm is 0.5 A. Thus it appears, in the case of $H\gamma$, that the actual effect is about one-and-one-half times the effect calculated for this field. It is commonly considered improbable that a Doppler effect can account for any appreciable portion of this difference.

Several plates taken by the writer during a recent examination of the Stark effect in a mixture of hydrogen and helium show second-order effects for $H\delta$ and $H\epsilon$. The Lo Surdo method was employed, and the light analyzed by a glass-prism spectrograph of high dispersion.[2]

Plate XII*a* is a reproduction of perpendicular components found in an analysis of $H\delta$ in fields up to 65 kv/cm. There is a general drift of the components toward the red in high fields. In the background numerous band lines appear, as well as the orthohelium line of the sharp series, λ 4121, displaced without separation at the extreme left. A comparison spectrum gives the positions of the undisplaced lines. The measured second-order shifts of the centers of gravity of symmetrical pairs of components of $H\delta$ at the maximum field of 65 kv/cm are as follows:

Pair of Components	Second-Order Shift of C.G. A
± 2	0.43
± 6	0.26
±10	0.51

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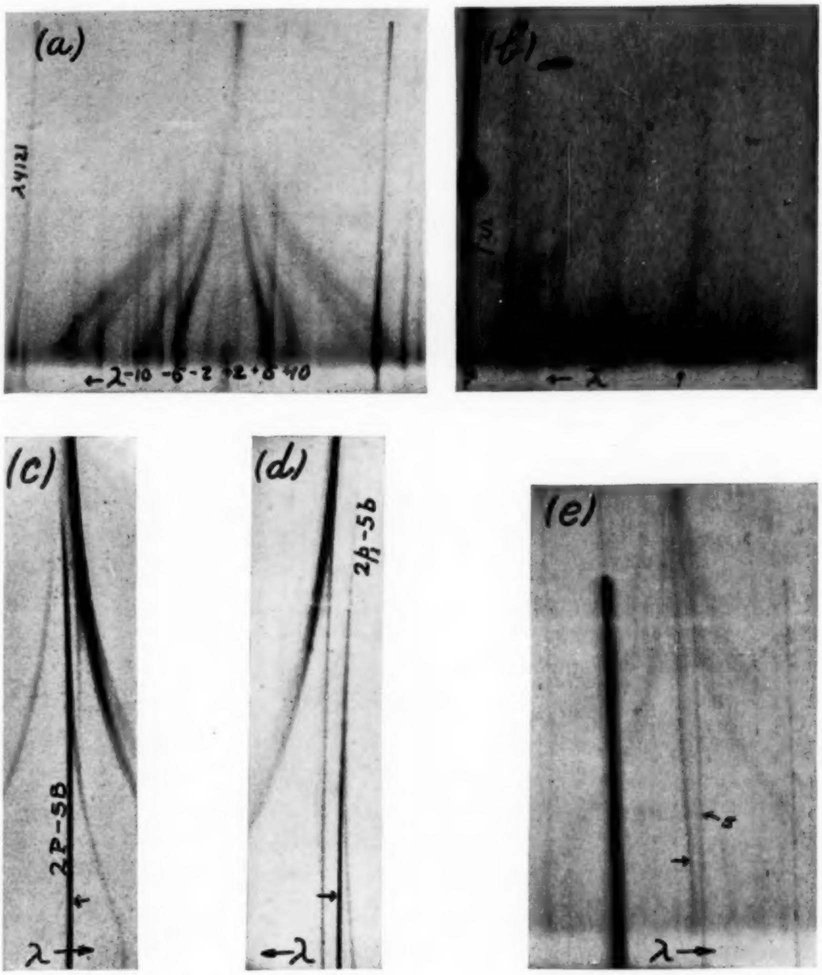
[1] *Annalen der Physik*, **65**, 36, 1921.

[2] *Journal of the American Optical Society*, **8**, 373, 1924.

PLATE XII



(*a*) *H*δ; perpendicular components; maximum field, 65 kv/cm
(*b*) *H*ε; perpendicular components; maximum field, 65 kv/cm
(*c*) Parhelium group, λ 4388
(*d*) Orthohelium group, λ 4026
(*e*) Parhelium group, λ 4009

Thus the observed average second-order effect for these six components of $H\delta$ is 0.4 A in a field of 65 kv/cm. The calculated value is $\left(\frac{65}{104}\right)^2 \times 0.73 = 0.3$ A. While these figures do not show a very good agreement between theory and experiment, there is a slight improvement over what we had in the case of $H\gamma$.

In Plate XII*b* a few perpendicular components of $H\epsilon$ are shown with considerably greater magnification. This line is weak on the original plate and a little out of focus. Arrows at the bottom of the photograph call attention to the central component and to a second moderately strong component having a slope of about 45°. The line marked *S* is an international standard line of the iron arc, λ 3981.776. It obviously has the curvature of a line unaffected by electric fields and characteristic of the prism spectrograph employed. After the photograph of the Stark effect had been taken, this line was admitted through a paper slide which masked the greater part of $H\epsilon$. The spectrograph was sufficiently rigid to prevent any disturbing motion of the plate between the exposures. In the absence of any undisplaced $H\epsilon$, the iron line serves as a convenient line of reference. The observed second-order Stark effect for the central perpendicular component of $H\epsilon$ is 0.73 A at 65 kv/cm. The calculated value is 0.79 A.

As $H\delta$ and $H\epsilon$ appear on the same plate, the data here presented are interpreted as experimental evidence that the second-order Stark effect is certainly real, and not merely a Doppler effect.

A possible application of this interesting phenomenon was suggested by Mosharrafa.[1] The theory claims that the central perpendicular component of $H\gamma$, like many other perpendicular components, is complex. In low fields it is believed to consist of two superimposed components, viz., 221→002 and 113→002. By reference to the Epstein formula, however, it is found that the calculated difference in second-order effects for these two components at 250 kv/cm is sufficient (0.02 A) to test this structure. The solution of this problem is possibly within the range of present experimental methods. The unresolved component is strong. Takamine has found the effect to be greater than that predicted, so that lower fields might suffice.

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[1] *Philosophical Magazine*, **44**, 371, 1922.

Finally, the components are sure to be sharp since no large displacements are involved.

In Plate XII*c* and *d* are reproduced photographs of the central portions of the analogous Stark effects for groups of helium lines, including the lines of the diffuse series, λ 4388 (parhelium) and λ 4026 (orthohelium). The diffuse lines alone are visible at zero field. Very weak fields, however, are sufficient to bring out the other lines in the groups as shown. The central components, which are displaced toward the red, are contributed by the combination lines $2P-5B$ and $2p_1-5b$, not by the diffuse lines themselves. These connections, first reported by H. Nyquist,[1] are now clearly reproduced in the accompanying photographs.

Recently the writer examined in some detail the Stark effect for the helium group λ 4009, comparable in a sense to $H\epsilon$. With much higher dispersion, it is now apparent that the central perpendicular component is displaced toward the red. The displacement amounts to 0.35 A in a field of 60 kv/cm. The behavior of the component may be followed by reference to the superimposed spectrum of an iron arc. The line marked *S* is the international standard λ 4009.718.

The extent to which a Doppler effect may enter into the displacements of hydrogen and helium lines in the strong fields established by the method of Lo Surdo is not completely determined. During this investigation, however, a satisfactory test was carried out, under stated conditions, in the case of neutral helium.

The experimental arrangement was essentially as follows. A discharge tube contained hydrogen and helium in about equal quantities and at a total pressure of 1.5 mm. The maximum field established during the test was 50 kv/cm. At λ 4026 the dispersion of the spectrograph was 1.8 A/mm. This group of lines (see Plate XII*d*) was selected for examination since the well-defined components could be measured to the nearest hundredth angstrom unit. The tube was inclined about 15° from the vertical in such a way that the positive ions had a velocity component (1) toward and (2) away from the slit. Upon careful comparison of the two plates so taken, no Doppler effect appeared. In the present experiments, which were temporarily

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[1] *Physical Review*, **10**, 226, 1917.

interrupted, no Balmer lines were on the plates showing the λ 4026 helium group.

Nevertheless, there is some less direct evidence of a possible Doppler effect. It lies in the fact that the Stark components of Balmer lines are much more diffuse than those components of neutral helium having equal displacements on the same plate. Many hydrogen band lines are greatly affected, and these, too, remain relatively sharp.

As a possible interpretation of these facts, we may reasonably assume that in this experiment the Balmer Stark components are produced by two classes of atoms: (1) those, like neutral helium, whose velocities are little affected by the high fields; and (2) a normally smaller number with various high velocities gained during their lives as positive ions. Assuming this to be the case, the thermal velocities of the first group will produce components with distributions of density differing only slightly from the neutral helium components of equal displacement; but the second group, with velocities no longer wholly unidirectional, might be expected to throw around the "normal" components a haze such as is actually observed in Balmer lines only. When the tube is inclined in the plane of the slit, the haze should show a Doppler effect while the "normal" distribution remains unchanged. This interpretation remains to be tested.

It may be noted that the available information on the second-order Stark effect indicates that as we pass to higher members in the Balmer series the observed effect approaches the value calculated by Epstein. In the absence of conclusive experimental evidence, we must admit the possible presence of a small Doppler effect blended with the true second-order effect in the observations. The former, if found, could not bring the theory and the present rough measurements into complete harmony.

In conclusion, I wish to express my best thanks to the National Research Council, U.S.A., for the opportunity to study Stark effects.

MACDONALD PHYSICS BUILDING
McGILL UNIVERSITY
December 7, 1925

W. H. JULIUS, 1860-1925

By A. EINSTEIN

With the passing away of W. H. Julius, one of the most original exponents of solar physics has left us. These few lines will be devoted to the work of this old friend of mine. They are written with the hope that his views on taking refraction into account in explaining solar phenomena may not be temporarily forgotten by oversight.

Julius began with his studies in mathematics and physics at the University of Utrecht in 1879. He directed his interest to experimental physics, working chiefly on emission and absorption in gases, until the age of thirty-one. Then, in 1891, a work of A. Schmidt, *Die Strahlenbrechung auf der Sonne, ein geometrischer Beitrag zur Sonnenphysik*, turned his attention to the field of solar physics, to which he thereafter devoted his entire life.

Julius did not advocate Schmidt's conception that the sharp edge of the sun was a phenomenon caused by refraction due to a radial density-gradient; for he recognized that scattering and absorption in the outer strata of the sun would necessarily prevent the formation of rays as long as those required by the Schmidt theory. He became convinced, however, that deviations from rectilinear propagation of light explained solar phenomena which would be difficult to comprehend if we ascribed to emission, absorption, and motion only, the distribution of light we see on the sun, and the velocity with which this distribution changes.

To do justice to the viewpoint of W. H. Julius, we must next ask what velocities are attained by matter in the outer strata of the sun. Observation gives no direct answer to this question. A priori, it is doubtful that motion of material is responsible for every shift of center of intensity of a spectral line, and for every motion of a singularity of intensity on the sun's disk. According to Julius, the only phenomena that give a direct measure of velocities of matter at the surface of the sun are sun-spots. That they are vortices is shown by the Zeeman effect found by Hale. Since familiar theorems of hydrodynamics show that the material of a vortex moves along with it, we may take the relative velocity of the spots as a velocity of matter. The velocities thus obtained average 0.15 km/sec., and never exceed 0.4 km/sec. Therefore Julius concluded, and in my opinion correctly, that we may not postulate essentially higher velocities in explaining solar phenomena.

Thus, for example, if the nuclei of granulations move with velocities of 3 to 4 km/sec. we may not think of the granulations as matter moving at such speeds. Julius viewed them as products of local variations of density of the solar atmosphere, accompanied by variable bending of rays from the photosphere. The velocities mentioned would thus be those of compressional waves, which actually are of that order of magnitude.

The distribution of intensity in sun-spots Julius likewise sought to trace back in an analogous way, at least in part, to refraction of light from the photosphere. To support such a view, he used among others an observation of Maunder, that far more spots, in the mean, appear on the eastern half of the sun's disk than on the western half. Julius explained this paradoxical finding by the slant produced in a vortex by inequalities (relative to latitude and depth) in the rotation of the sun. The upper portion comes to precede the rest of the vortex, thus inclining its axis at various angles to the line of sight, refraction being most manifest when this angle is small.

Prominences and the chromosphere Julius also sought to ascribe to variations of density (gradients) occurring in the outer part of the solar atmosphere. The transient motion observed in prominences, with velocities of image as high as a few hundred kilometers per second, he ascribed to minor displacements of density-gradients. He thought of the light as originating in the chromosphere, and being influenced by strong refraction in the close vicinity of an absorption line.

Julius' conception of the origin of Fraunhofer lines seems to me to be of particular importance. The observed lines are much broader than mere absorption lines corrected for Doppler effect. The broadening is explained by molecular scattering, and (chiefly) by anomalous refraction in irregular strata of gas. Because of the high refractive power near the absorption line of a substance, anomalous refraction must limit emission just as molecular scattering does.

But in contrast with the latter, the former causes an asymmetrical broadening of the lines. Julius thus explained shifts which, ascribed to a Doppler effect, called for improbably large velocities varying from line to line. In the same way he explained why the shift toward the red observed in the center of the sun differs from that at the periphery. He believed that the entire observed displacement of lines toward the red had to be explained in this way, and, therefore, held the opinion that the shift required by the theory of relativity does not exist.

I am not competent to render judgment on the reach of Julius' ideas, but I believe that they deserve careful consideration, particularly in the discussion of shifts in spectral lines. These few remarks will have served their purpose if they bring anew to the attention of the profession the work of this clear-sighted, artistically fine-spirited man.

NATUURKUNDIG LABORATORIUM DER RIJKS-UNIVERSITEIT
LEIDEN
December 14, 1925

REVIEWS

Vorlesungen über Atommechanik. By MAX BORN, with the collaboration of FRIEDRICH HUND. ("Struktur der Materie in Einzeldarstellungen," 2.) Volume I. Berlin: Julius Springer, 1925. Pp. ix+358. Figs. 41.

The present volume is a compilation of a series of lectures delivered in 1923–1924 by Professor Born at Göttingen. So far the only books on this subject are Professor Sommerfeld's magistral *Structure of the Atom and Spectral Lines,* which enables the reader to follow in an elementary way the development of the atomic theories, and L. Brillouin's *La théorie des Quanta et l'Atome de Bohr.* But there was a need for a purely systematic mathematical introduction to modern atomic theories. This has now been realized by Professor Born in a very appropriate and elegant manner.

As implied by its name, *Atomic Mechanics,* the work explains the phenomena in atomic physics from the special standpoint of the application of mechanical principles, just as in celestial mechanics the study of the motions of the heavenly bodies is deduced from purely mechanical laws. In this first volume are considered only questions within the limits of the validity of the principles characterizing in their present state the atomic and quantum theories. But Professor Born hopes later to supplement this first part by a second volume, when a closer approximation to a more definite theory will have been reached.

After an Introduction containing the physical basis of the theory, the book is divided into four chapters. In the first chapter, the Hamilton-Jacoby theory is developed in a masterly manner. The second chapter deals with the periodic systems of one and more degrees of freedom; and the adiabatic invariance of the action variables, the quantum conditions, and the correspondence principle are fully explained. Both the preceding chapters show in a splendid manner all the allurements of the theory. The third chapter is entitled, "Systems with One Series Electron." It may be called a specialization to a central field of what is developed in the preceding chapter. It contains a systematic account of the development of the theory of the hydrogen-like atom and the theoretical meaning of the Rydberg and Ritz series formulae, which secured the immediate and great success of Bohr's work. The question of the polarizability of the core is explained according to Born and Heisenberg's own investigations. Besides an account of the true quantum numbers of the optical elements and the constitution of the periodic system of elements, important consideration is given to the Zeeman and the Stark effects and the difficult analysis of the motion of the hydrogen atom in the crossed electric and magnetic fields. In the fourth and last chapter an account is given of the theory of perturbations.

Throughout the work numerous applications are systematically treated. The literature of the subject has been enriched by Professor Born's contribution in a most valuable manner. There is no doubt that this book will have a great success among all mathematical students of the atomic theory.

H. L. VANDERLINDEN

Nei Cieli: Pagine di Astronomia Popolare. By PIETRO CARDINALE MAFFI. Torino: Società Editrice Internazionale, 1923. 8vo. Pp. 312. 120 cuts and 3 plates. 30 lire.

One would perhaps not think of a prince of the Roman Church as likely to be the author of works on astronomy, though the list of less highly placed ecclesiastics of that communion who have devoted themselves to the celestial science is a long and honorable one. And especially now, when a librarian, archivist, paleographer (and mountain-climber) has been made pope, there is certainly no reason why another ecclesiastic should not be both astronomer and cardinal. There is in the fact a tribute to the nobility of the science. Indeed, a peculiar fitness may be seen in the circumstance that His Eminence is Archbishop of Pisa, and before his throne sways the long pendant of Posenti's lamp, whose movements are said to have suggested to Galileo his discussion of the pendulum.

Cardinal Maffi is no novice in the field, nor does his book owe any of its well-recognized popularity to the distinguished ecclesiastical position of its author. The first edition was issued nearly thirty years ago. The present edition is the fourth, which, like its immediate predecessor, has been revised, enlarged, and in many small ways brought up to date by another priest, Don Francesco Faccin, whose sudden death shortly before the publication of the book gives occasion for a touching preface in his memory by his friend, the author. Faccin's task appears to have been very conscientiously carried out, and with competent knowledge of recent discoveries and new theories. Even the modifications of former conclusions necessary if Einstein's doctrine of relativity is accepted are given proper consideration.

The Cardinal's choice of subjects and limitation of their range is eminently judicious. It avoids the extreme of such mathematical discussion of problems of celestial mechanics as would be impossible for any but a technically trained reader to follow. Indeed, he hardly goes beyond geometry in his actual formulas. On the other hand, he shuns the contrary extreme, and by no means attempts to avoid mathematics altogether, nor permits himself to sink into mere rhetorical description. His style is admirable—clear and simple in exposition, sympathetic and charming in manner, but without waste of words. Diagrams and other illustrations are well chosen and sufficient, though the reproductions of photographs are not so good as those to which we are accustomed in this country. The maps of the stellar hemispheres are clear and usable, though of necessity somewhat crowded. For use by foreigners (and I should think even by Italians) it would have been better to have the names of the stars and constellations in their Latin forms.

The proofreading is in general excellent, but somewhat capricious in regard to proper names in German and English. It is curious, by the way, not to find our Burnham mentioned specifically among the half-dozen indicated as discoverers and measurers of double stars. The work of Messrs. Barnard and Parkurst (*sic*) is duly recognized, as is that of other American astronomers. But it would have been better if all names cited had been included in the Index, or, better yet, in an index by themselves.

Having often no more absorbing occupation, I have read in the course of years a considerable number of manuals of "popular" astronomy. I should put this of Cardinal Maffi high up in the list, preferring to it perhaps only the Newcomb-Engelmann *Populäre Astronomie,* chiefly on account of the fuller content of the latter work.

A concluding remark or two may be permitted.

Is the light of Mercury any more steady in general than that of Venus at almost its worst "boiling-point" (p. 11)? Not in my experience; and here at my southern California station I have had, and am just now having, favorable opportunities to observe both.

The Cardinal repeats (p. 11) what has often been said by others, that the horizon *appears* to be circular in outline. I have never been able to agree that this is an immediate datum of vision, as when, for example, from a position far removed above its plane, we look down upon a circle described on a piece of paper. At a given moment the observer's eye can attend to only a small portion of the horizon, and this looks to me precisely like a straight line. A succession of such observations carried from point to point around the complete periphery gives no more certain and immediate impression of the figure being a circle than it does of its being a many-sided polygon. The conviction that it *is* circular appears to me to be the result of a combination of inferences and not one of plain vision. We are too nearly in its plane to *see* it so.

Also the Cardinal agrees with others in remarking that the vault of heaven *appears* to us, not as hemispherical, but as oblately spheroidal, "flattened down over our heads." I certainly have no such ocular impression of the shape of the vault. If anything, stars of low elevation seem nearer than those in the vicinity of the zenith.

I find it very difficult to believe that any of the asteroids can possibly be surrounded by an atmosphere. Even if we suppose that they had one to start with (whatever their origin), how could objects of such small mass have retained such a thing till the present age?

ELMER T. MERRILL

Konstanten der Atomphysik. By W. A. ROTH AND K. SCHEEL, with the special collaboration of E. REGENER. Berlin: Julius Springer, 1923. Pp. 114.

These tables are an abstract from the fifth edition by Roth and Scheel of Landolt-Bornstein's important *Physical-Chemical Tables.* Besides a list of atomic weights for 1923, thirty-two tables form the contents of this little volume. They are headed successively as follows:

1. Periodic System of the Elements
2. Mixtures of Isotopes with a Constant Combination Weight Occurring in Nature and Pure Elements
3. Radioactive and Corresponding Inactive Isotopes
4. The Radioactive Elements
5. Thermal Effect of Radioactive Substances
6. Determination of the Age of Minerals
7. Mutual Ratio of the Different Mass Units of Energy
8. Velocity of Light *in Vacuo*
9. New Determination of Loschmidt's Number N
10. Velocity, Length of Path, and Dimensions of Gas Molecules
11. Tables of Minimum Thickness of Films
12. Literature concerning Gas Molecules and Minimum Thickness of Films
13. Elementary Electric Quantum, Electrochemical Equivalent and Some Constants Derived from Them
14. Specific Charge of the Electron

15. Planck's Action Element
16. Constants of Radiation
17. Wave-Lengths and Spectral Regions in the Entire Spectrum
18. Infra-red Wave-Lengths
19. Tables and Atlases of Photographic Spectra
20. Optical Series Spectra of Some Elements
21. Tension of Excitation and Ionization for Mono- and Polyatomic Gases and Vapors
22. Term Numbers in Spectral Series
23. Absorption and Scattering of Roentgen-Rays
24. Structure of Crystals
25. Mobility of Ions in the Principal Gases and Vapors
26. Coefficient of Diffusion of Ions in Gases
27. Coefficient of the Mutual Recombination of the Ions in Different Gases
29. Potential Fall at the Cathode in Fluorescence Discharge
30. Passage of Electrons (Cathode Rays, β-Rays) through Matter
31. The Limits of Long Waves of the Photo-Electric Action in the Red
32. Resonance Wave-Lengths of the Selective Photo-Electric Action

The name of the compiler is indicated under each table, and all necessary references are included. The concise form and clearness of the tables will prove to be very handy for the use of all investigators interested in atomic theories.

H. L. VANDERLINDEN

Physico-Chemical Evolution. By CH. EUG. GUYE. Translated by J. R. CLARK. New York: E. P. Dutton & Company, 1925. Pp. xii+171. 4 Figs. $2.40.

Because they all depend upon the same concepts of number, space, time, and matter, the four sciences of mechanics, physics, chemistry, and astronomy are classified by Professor Guye in a group which he designates as physical chemistry. One of the most important principles applicable to these sciences is the second law of thermodynamics. Though this law has met every experimental test, arguments based upon the kinetic theory have justified the conclusion that its apparent exactness is a consequence of its application only to those experiments in which very large numbers of elements are involved. According to this notion, the second law describes only the average or statistical behavior of large numbers of molecules; it is not applicable to the actions of individual molecules or to very small numbers of them. The significance of this modern view of the Carnot principle is the subject of the essays which constitute *Physico-Chemical Evolution*.

Many analogies and illustrative examples are included in the book. They contribute much to the clarity of the discussions and to the pleasure of the reader. On one page he finds spinning roulette wheels, on another a million monkeys operating a million typewriters. Extensive use is made of a tube containing powders of two colors. Shaking usually results in the mixing of the powders. Continued shaking ordinarily produces no additional change in the appearance of the mixture, although the relative positions of the particles are repeatedly altered. If the number of the particles is very small, however, continued shaking may, on rare occasions, result in a partial or even complete separation of the two colors. Similarly, a separation might occur in an experiment made with a much larger number of particles, but it would be much less probable, and consequently much more rare. The probability of the separation of several thousand particles from a similar number of another kind is so small as to amount to an impossibility in so far as any ordinary laboratory experiment is concerned.

In the third paper of the series the author considers the application of his arguments to biology, which he considers a more general science than physical chemistry. In a few preliminary remarks the reader is reminded that living things are not heat engines, and that experiments performed on plants and animals have revealed no violation of the Carnot principle. The living cell may perhaps be too large to escape rigorous compliance with the second law. Nevertheless, it is possible that there may be important exceptions to the law as originally stated. In some of the very small delimited regions which make up the granular contents of a cell, there may be rare deviations or fluctuations from average behavior. The author suggests that these may account, if not for normal individual development, at least for nonconformity with the usual plans of growth and perhaps for the evolution of the species.

Both the author and the translator are to be thanked for making the book available to those who are enjoying it, and to the many who are to do so. Though neither the statistical view of the second law nor the application of the view to the phenomena of life are new suggestions, the book contains valuable expansions of these ideas which have created much interest. Here is a valuable treatise for those students of thermodynamics who wish to expand and clarify their notions of the statistical view of the second law. The speculations and suggestions concerning the significance of the Carnot principle will prove of great value to all those interested in science in general. They will find the book inspiring and very suggestive.

T. F. YOUNG

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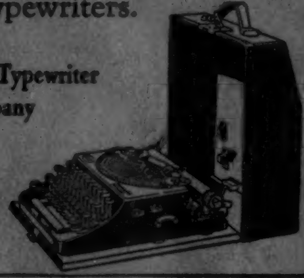

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